Embedded Linux
Hands-on Tutorial -- ZedBoard

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This *Embedded Linux Hands-on Tutorial* for the *ZedBoard* will provide step-by-step instructions for customizing your hardware, compiling the Linux Kernel and writing driver and user applications. This documentation intends to integrate knowledge and skills in FPGA logic circuit design, standalone software programming, and Linux operating system and software development, and apply them to the ZedBoard.

In this tutorial, we will start from the *ZedBoard Linux Hardware Design* (available on the ZedBoard product page of the Digilent website). The system architecture for the *ZedBoard Linux Hardware Design* is shown in Figure 1.

In the *ZedBoard Linux Hardware Design*, we connect UART1 to USB-UART, SD0 to the SD Card Slot, USB0 to the USB-OTG port, Enet0 to the Giga-bit Ethernet Port, and Quad SPI to the on-board QSPI Flash. These cores are hard IPs inside the Processing System (PS) and connect to on-board peripherals via Multiplexed I/O (MIO) pins. The use of PS GPIO is a little bit more complicated. We connect the lower bits of PS GPIO via MIOs to Button 8, 9, LED 9, and Pmod JE, while the higher bits of PS-GPIO are connected via Extended MIOs (EMIO) to 5 push buttons, 8 LEDs, 8 slide switches, Pmods JA to JD, and the on-board OLED module. In the Programmable Logic (PL), we have an HDMI Tx Controller, VDMA, SPDIF, and IIC IP cores to talk to the ADV7511 HDMI Transmitter Chip and I2S and IIC IP Cores for ADAU1761 Audio Codec. More details of the hardware design can be found in the documentation inside the *ZedBoard Linux Hardware Design* package.

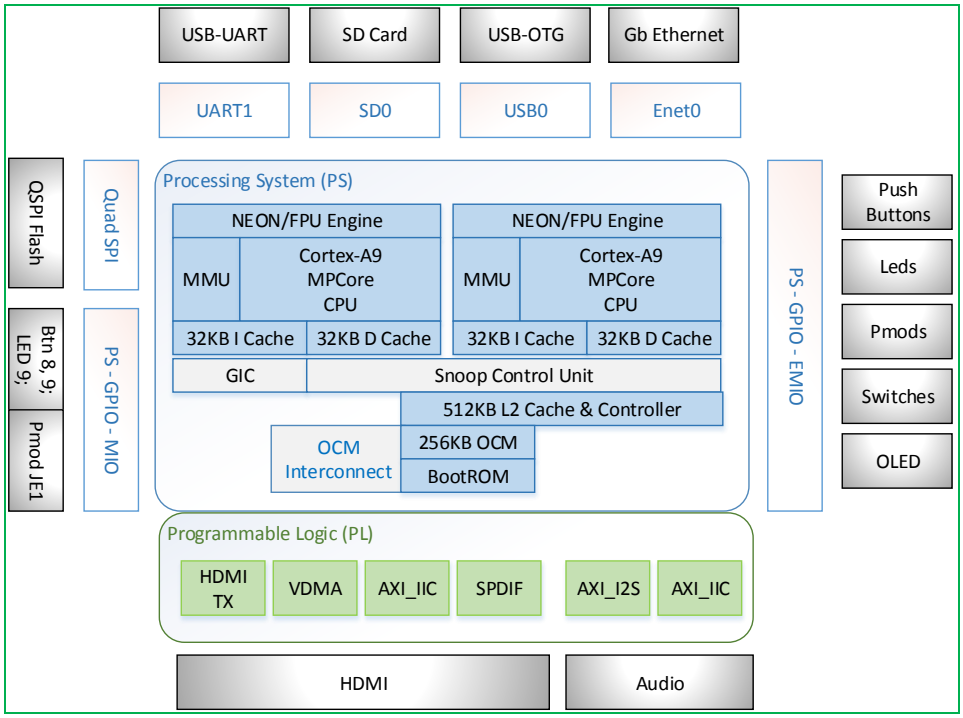


Figure 1. ***Reference Basic Hardware System Architecture for ZedBoard***

In this tutorial, we are going to detach the LEDs from the PS GPIO core and implement our own *myled* core for it in PL, as shown in Figure 2. We will then add our own LED controller into the device tree, write a driver for it, and develop user applications to control the status of the LEDs.

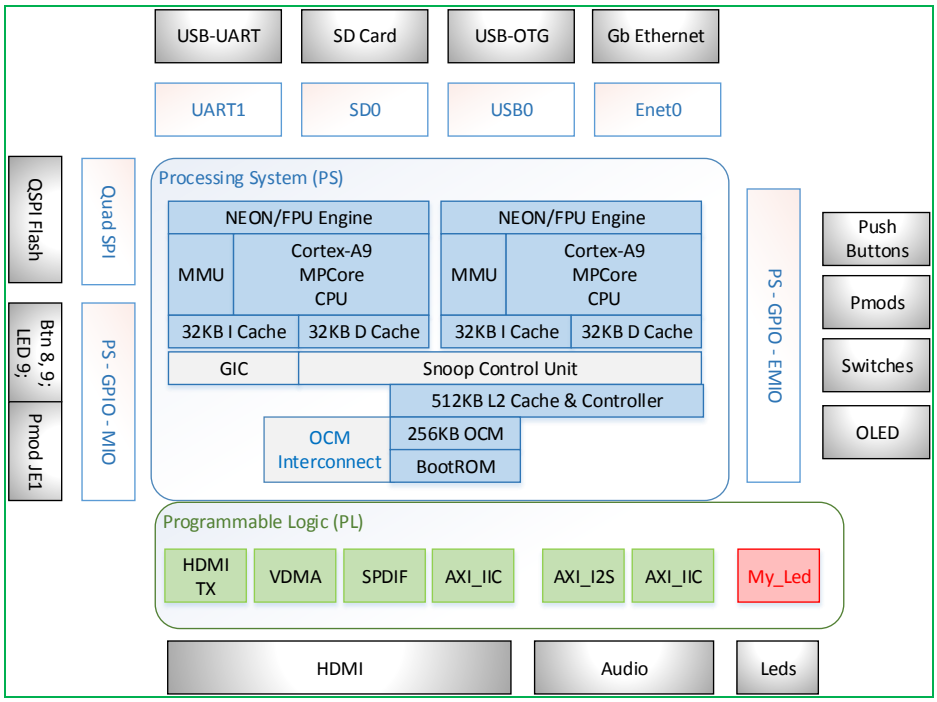


Figure 2. ***Hardware System Architecture of the system we are going to implement in this Tutorial***

Before going through this tutorial, we recommend that you read *Getting Started with Embedded Linux -- ZedBoard* first. You can follow this tutorial with the *Embedded Linux Development Guide* (available on the Digilent Website Embedded Linux Page). The guide will provide you with the knowledge you may need in each step of the development.

In this tutorial, we are going to use **Xilinx ISE DS 14.4** in a Linux environment. All the screen shots and codes are done using **Xilinx ISE DS 14.4 x64 Edition** in **CentOS 6.2 x86_64**.

That's it for the background information on this tutorial, now it's time to get our hands dirty with some real design!

Section I: Hardware Customization

Prerequisites

- **Xilinx ISE DS 14.4 (WebPack)**
  available at Xilinx Website Download Page

- *ZedBoard Linux Hardware Design*
  available at Digilent Website ZedBoard Page

Instructions

I-1 Download the *ZedBoard Linux Hardware Design* from the website and unzip it into our working directory (our working directory is named *tutorial* throughout this tutorial). See Example 1. For more information on the hardware design, please refer to *Project Guide* under `doc` folder.

Example 1.

```
[tinghui.wang@DIGILENT_LINUX Tutorial]$ unzip ~/Downloads/ZedBoard_Linux_Design.zip
Archive:  /home/tinghui.wang/Downloads/ZedBoard_Linux_Design.zip
  …
  inflating: ZedBoard_Linux_Design/sw/hw_platform/ps7_init.html
  inflating: ZedBoard_Linux_Design/sw/hw_platform/ps7_init.tcl
  inflating: ZedBoard_Linux_Design/sw/hw_platform/system.xml
   creating: ZedBoard_Linux_Design/sw/zynq_fsbl/
   creating: ZedBoard_Linux_Design/sw/zynq_fsbl/src/
  inflating: ZedBoard_Linux_Design/sw/zynq_fsbl/src/main.c
[tinghui.wang@DIGILENT_LINUX Tutorial]$
```

I-2 Source Xilinx ISE 14.4 settings and open the design with **Xilinx Platform Studio** (**XPS**). See Example 2. You will see the **XPS** window pop up as shown in Figure 3.

Note: There are four settings files available in the Xilinx toolset: `settings64.sh` for use on 64-bit machines with bash; `settings32.sh` for use on 32-bit machines with bash; `settings32.csh` for use on 32-bit machines with C Shell; and `settings64.csh` for use on 64-bit machines with C Shell.

Example 2.

```
[tinghui.wang@DIGILENT_LINUX Tutorial]$ source /opt/Xilinx/14.4/ISE_DS/settings64.sh
. /opt/Xilinx/14.4/ISE_DS/common/.settings64.sh /opt/Xilinx/14.4/ISE_DS/common
. /opt/Xilinx/14.4/ISE_DS/EDK/.settings64.sh /opt/Xilinx/14.4/ISE_DS/EDK
. /opt/Xilinx/14.4/ISE_DS/common/CodeSourcery/.settings64.sh
/opt/Xilinx/14.4/ISE_DS/common/CodeSourcery
. /opt/Xilinx/14.4/ISE_DS/PlanAhead/.settings64.sh /opt/Xilinx/14.4/ISE_DS/PlanAhead
. /opt/Xilinx/14.4/ISE_DS/../../Vivado/2012.4/.settings64.sh
/opt/Xilinx/14.4/ISE_DS/../../Vivado/2012.4
. /opt/Xilinx/14.4/ISE_DS/ISE/.settings64.sh /opt/Xilinx/14.4/ISE_DS/ISE
. /opt/Xilinx/14.4/ISE_DS/../../Vivado_HLS/2012.4/.settings64.sh
/opt/Xilinx/14.4/ISE_DS/../../Vivado_HLS/2012.4
[tinghui.wang@DIGILENT_LINUX Tutorial]$ xps ZedBoard_Linux_Design/hw/xps_proj/system.xmp &
[tinghui.wang@DIGILENT_LINUX Tutorial]$
```

I-3 We are going to detach LEDs from the GPIO core in the PS first. So, we need to click on the **I/O Peripherals** (red circle in Figure 3), and a **Zynq PS MIO Configuration** window will pop up as shown in Figure 4. We are going to change the width of GPIO on **EMIO** interface from **60** to **52** to remove 8 LED pins, as shown in the red circle in Figure 4. However, we also need to refresh the change in the **External Ports** section of the **Ports** tab. So, click **Ports** tab, expand processing_system7_0, expand **(IO_IF) GPIO_0**, disconnect it from **External Ports**, and connect it to **External Ports** again, and remove the **_pin** from the name (as shown in Figure 5). We will handle the modification of external pin location configuration (**ucf** file) in later steps.

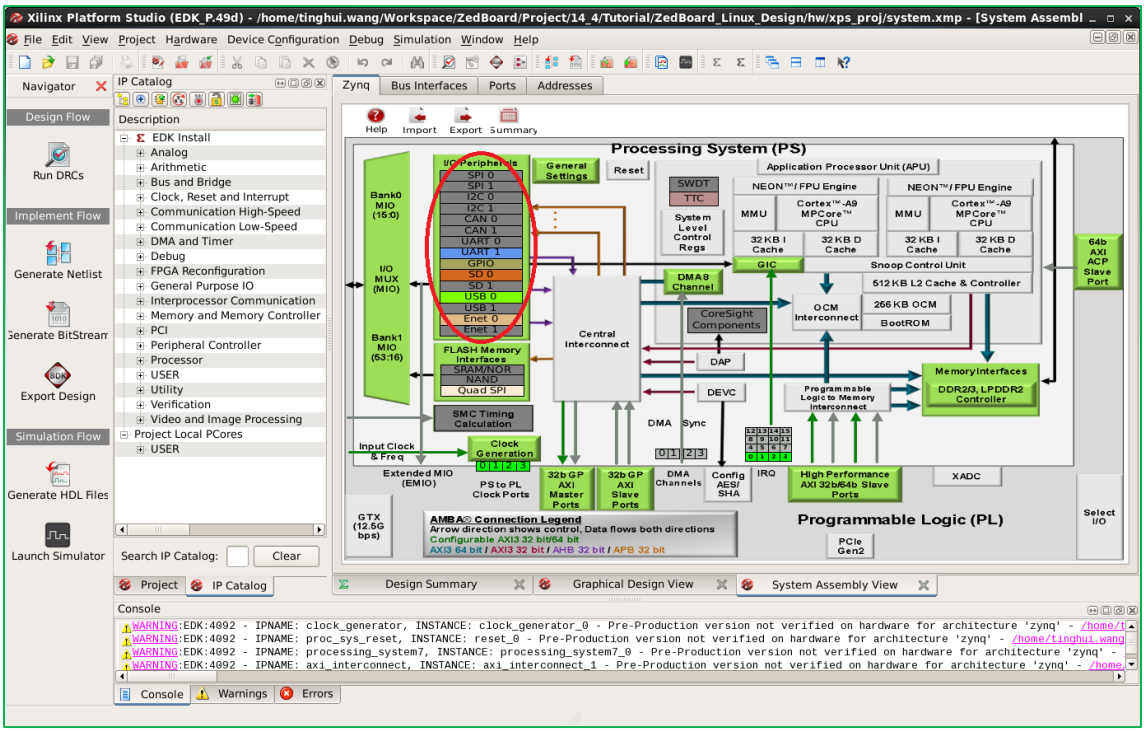


Figure 3. ***Xilinx Platform Studio GUI***

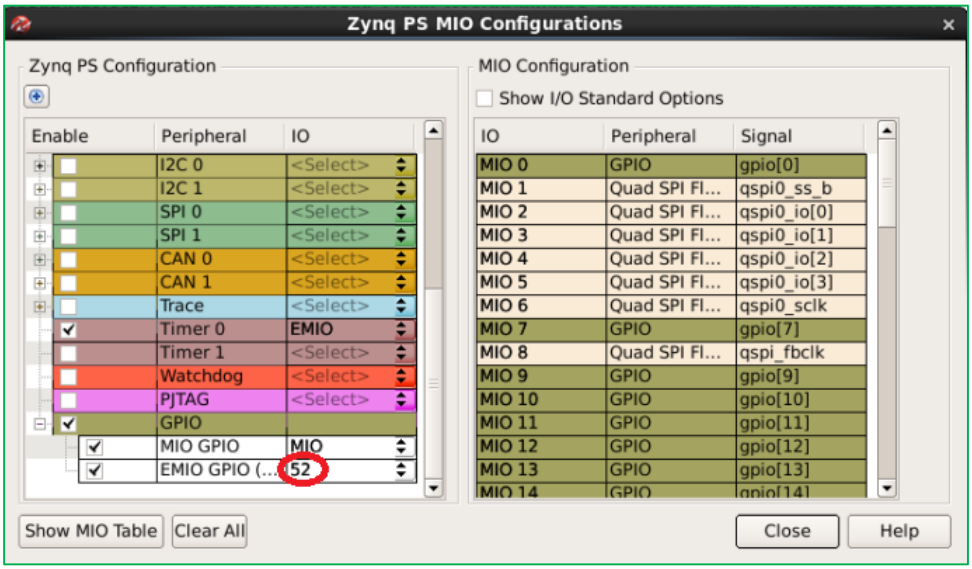
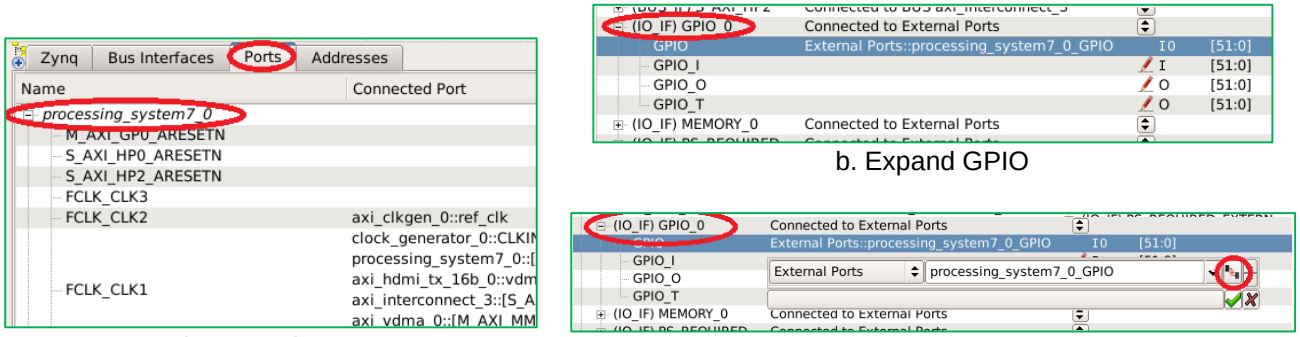


Figure 4. ***Zynq PS MIO Configurations***



a. Expand *processing_system7_0*

b. Expand GPIO

c. Disconnect GPIO from External Ports

d. Make GPIO External again

Figure 5. Reconnect GPIO to External ports

I-4 Now we can start implementing our `myled` IP Core. Click **Hardware -> Create or Import Peripheral…** from the menu (as shown in Figure 6). The **Create and Import Peripheral Wizard** window will pop up (as shown in Figure 7). Click Next.

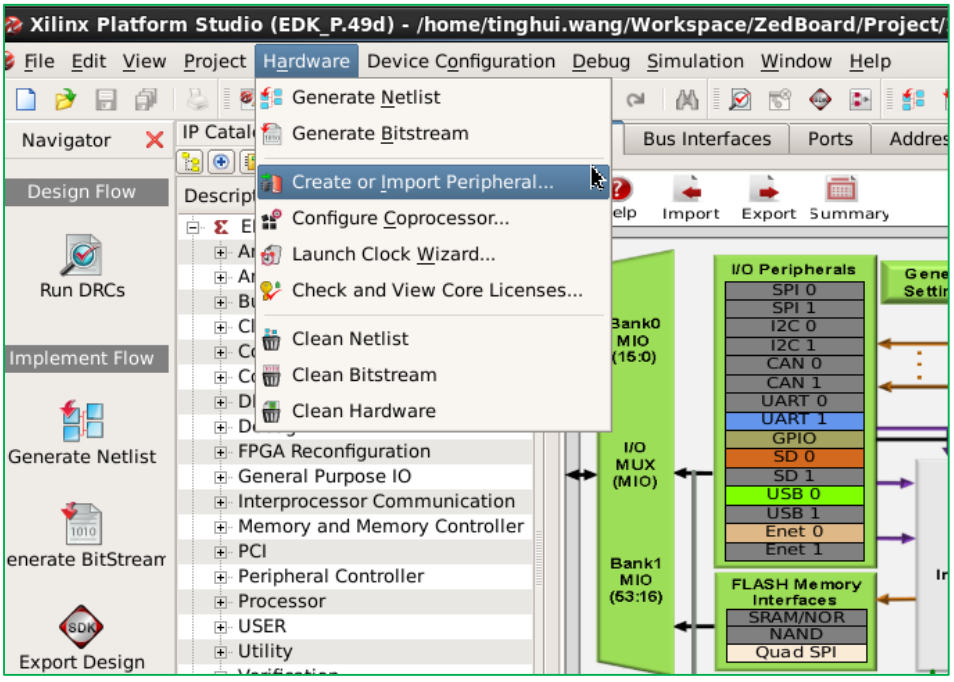


Figure 6. Start Create or Import Peripheral Wizard

Figure 7. ***The Create and Import Peripheral Wizard Window***

I-5 In the Peripheral Flow, we select **Create Templates for a New Peripheral** (as shown in Figure 8). Click Next.

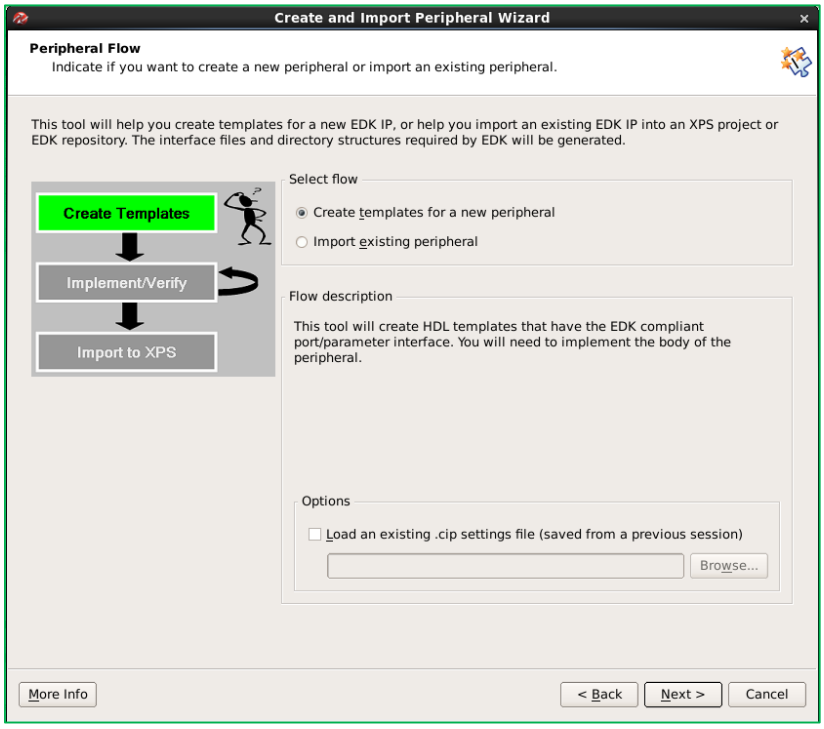


Figure 8. Select Peripheral Flow

I-6 We chose to store the IP core into this project folder (as shown in Figure 9). As a result, you will find `myled-1.00.a` within the `pcores` folder. Click Next.

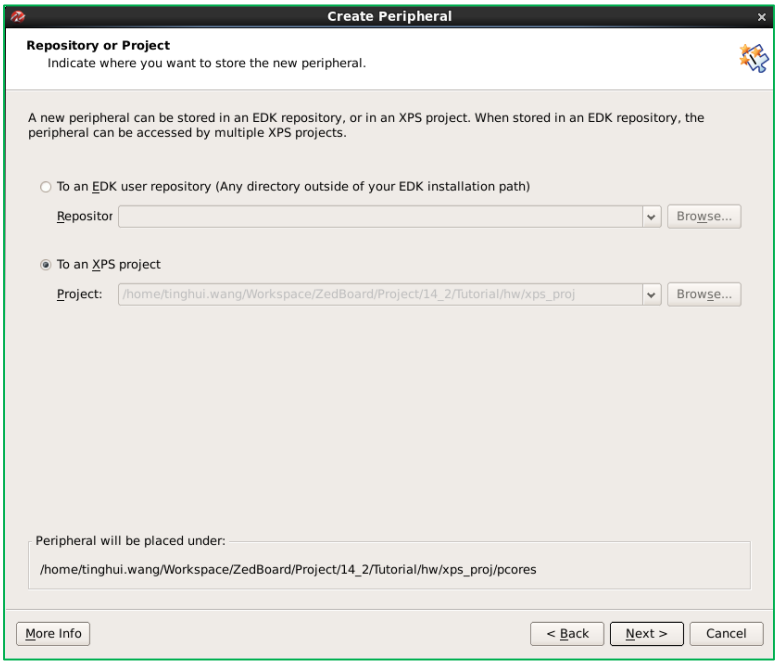


Figure 9. Store New IP Core in current XPS project

I-7 Fill in the name of the IP, and add your description of this IP core (as shown in Figure 10). Click Next.

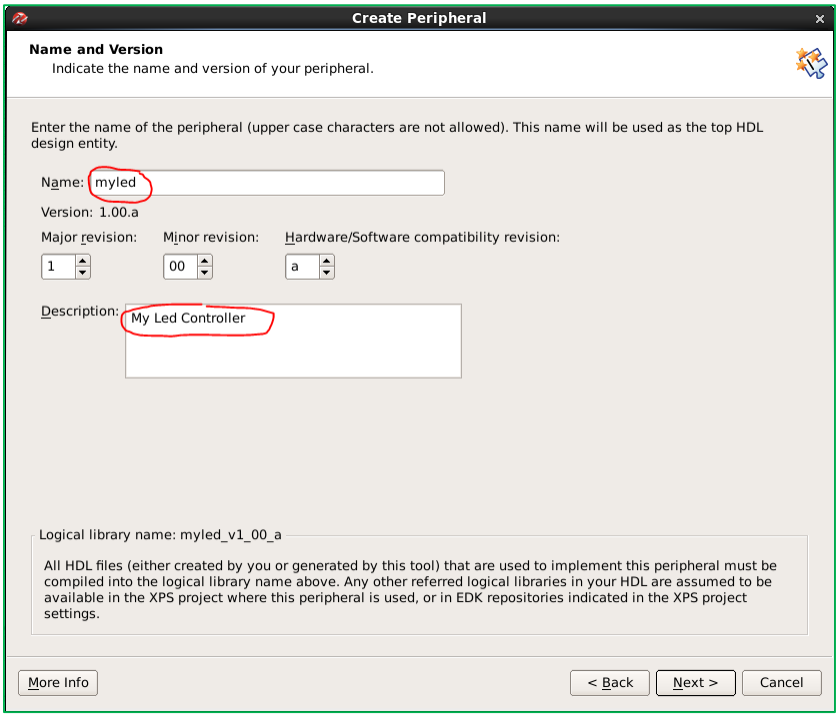


Figure 10. Fill in the name and description for the new IP Core

I-8 In Bus Interface, we will use AXI4-Lite. So, select **AXI4-Lite** and Click Next (As shown in Figure 11).

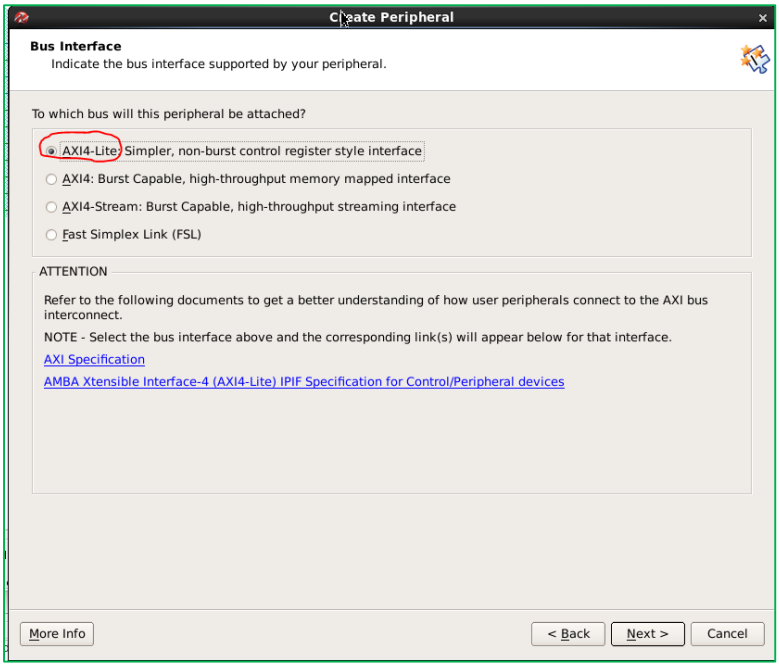


Figure 11. Select AXI4-Lite for Bus Interface

I-9 In IP Interface Service, the only thing we need is one software register. So, select **User Logic Software Register**, and deselect **User Logic master Support**, **Software Reset** and **Include Data Phase Timer** (as shown in Figure 12). Click Next.

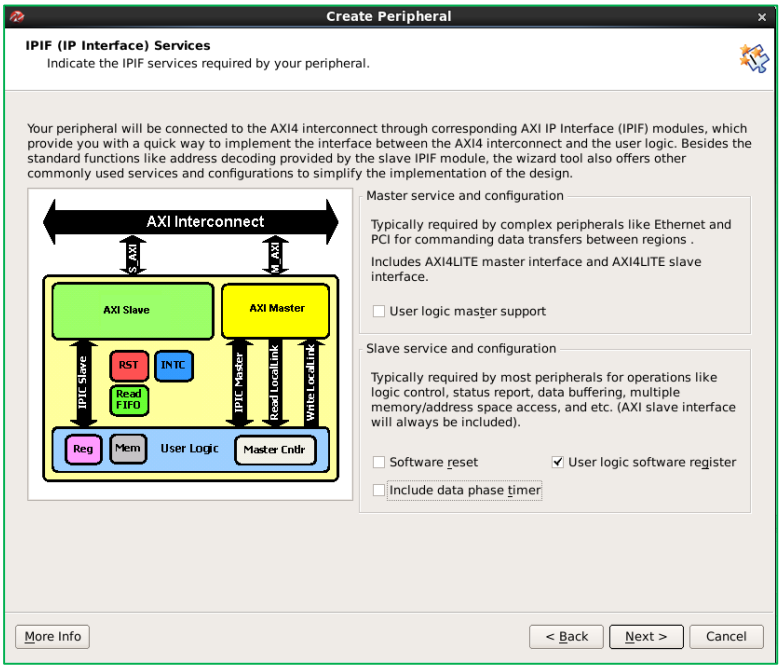


Figure 12. IP Interface Service Configuration

I-10 In our design, we only need 8 bits to control 8 LEDs. So, we only need **One** 32-bit register, and we will use the lower 8-bits in our design. In User S/W Register Configuration, type **1** in the box besides **Number of software accessible registers** (as shown in Figure 13). Click Next.

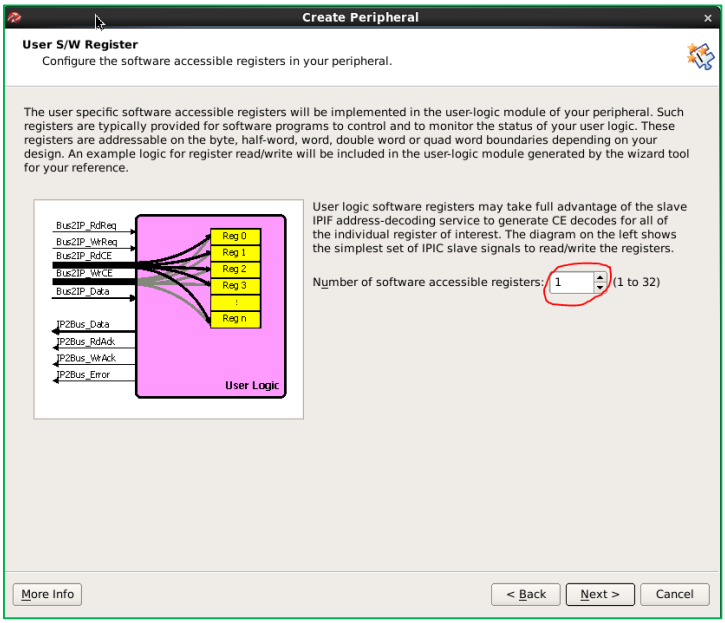


Figure 13. User S/W Register Configuration

I-11 Keep default options selected for **IP Interconnect Configuration** and **Peripheral Simulation Support**. If you want to use *Verilog* instead of *VHDL* (default), check the box beside **Generate stub 'user_logic' template in Verilog instead of VHDL** in **Peripheral Implementation Support** (as shown in Figure 14). Click **Next**, and then click **Finish**.

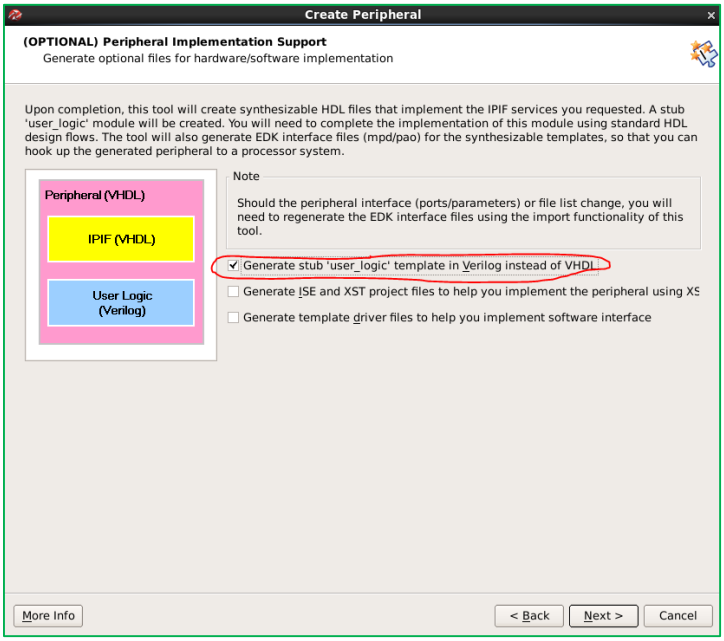


Figure 14. (OPTIONAL) Peripheral Implementation Support Configuration for Verilog Users

I-12 We are going to add our IP to our design. You will find the IP core in the **IP Catalog** Panel under **Project Local PCores -> USER -> MYLED 1.00.a**. Right click on it and Click **Add IP** (as shown in Figure 15.

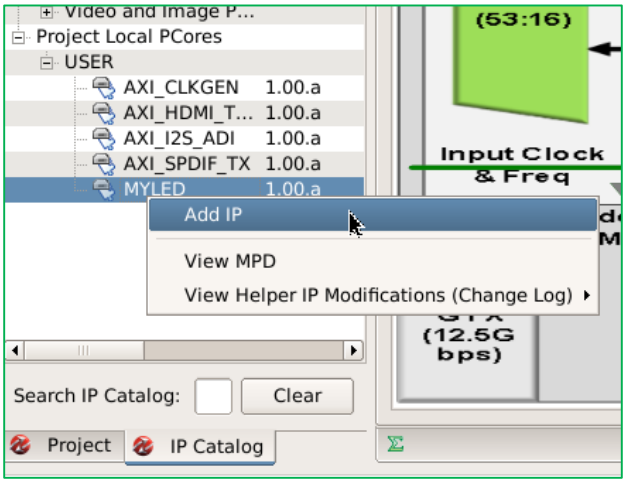


Figure 15. Add MYLED to your design

I-13 In the pop-up **XPS Core Configuration** window, keep everything as default (as shown in Figure 16), and Click OK.

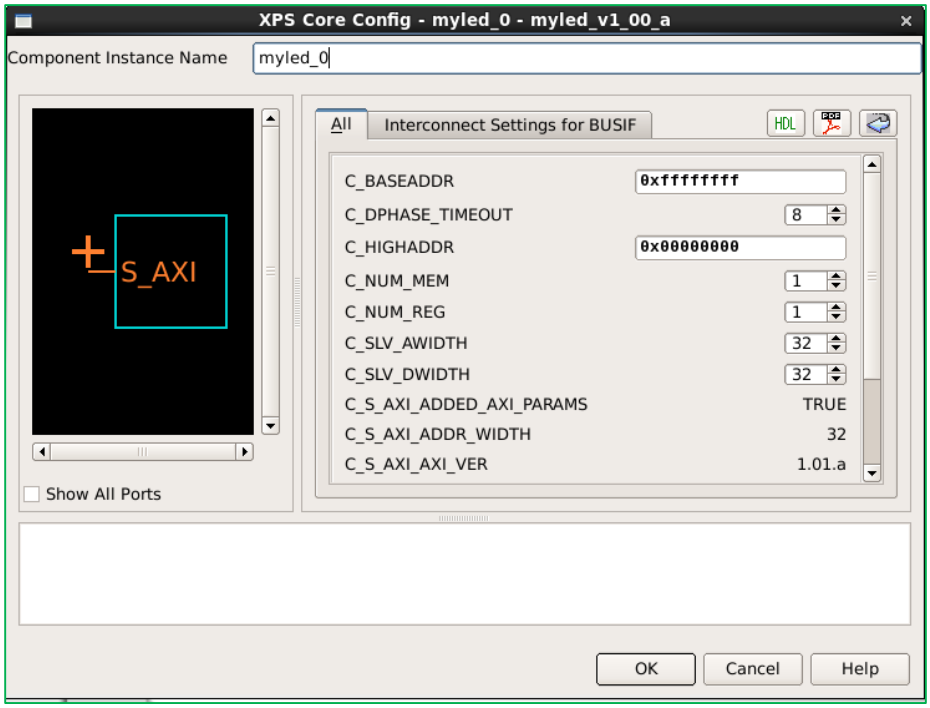


Figure 16. XPS Core Configuration for myled

I-14 The AXI4-Lite bus of `myled` IP Core needs to be connected to the processing system. So in **Instantiate and Connect IP** window, check **Select Processor Instance to Connect To**, and select **processing_system7_0** in the drop down box (as shown in Figure 17). Click OK.

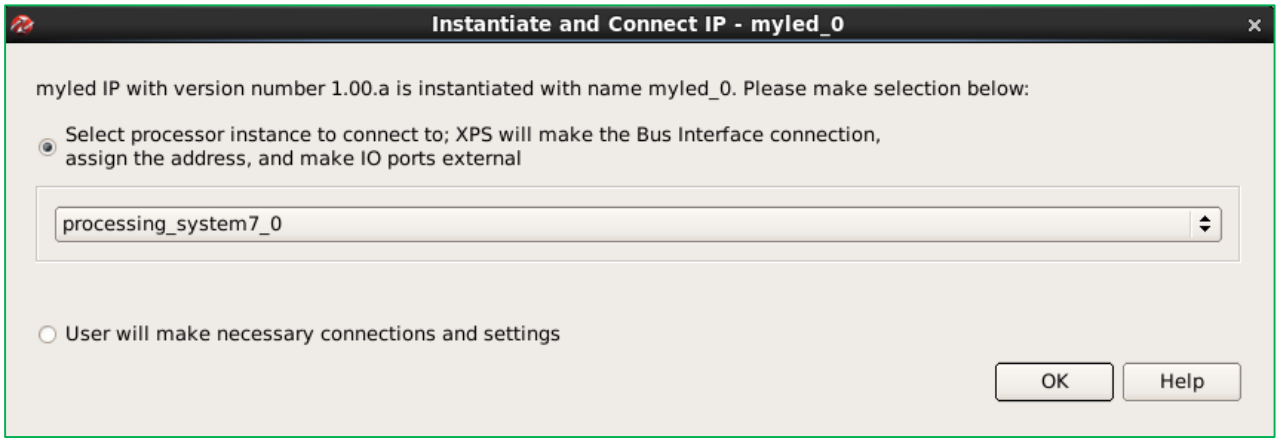


Figure 17. Instantiate and Connect MYLED IP

I-15 You will see an IP named `myled_0` is added to your system with **S_AXI** connected to **axi_interconnect_1** as shown in Figure 18.

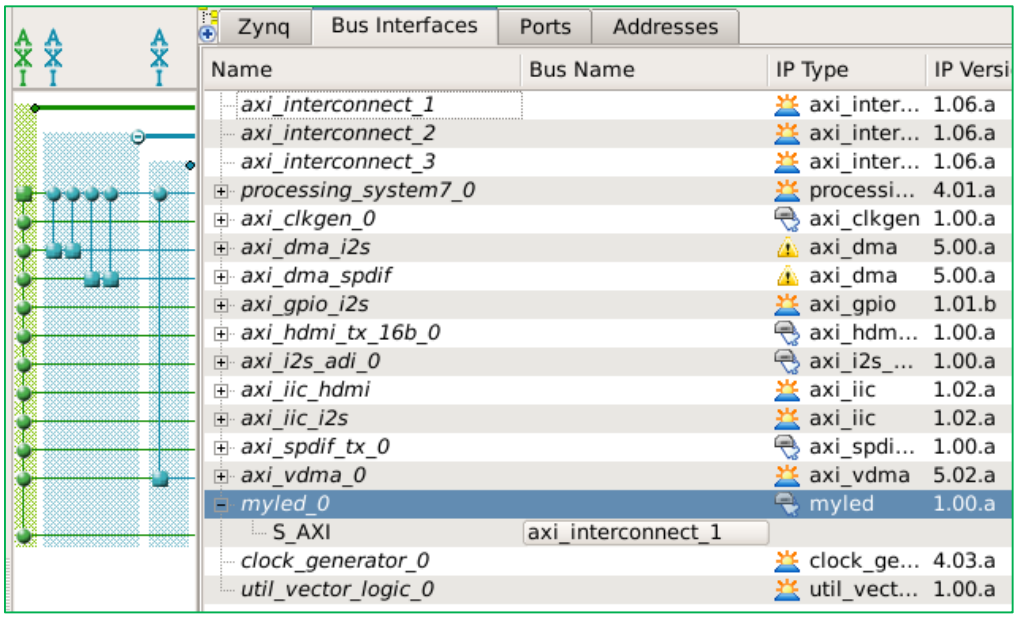


Figure 18. MYLED IP shows up in the design

I-16 Now we are going to implement the circuit using HDL. The `myled` IP Core Template will generate two HDL files corresponding to two modules: `myled`, and `user_logic` (as shown in Figure 19). Module `myled` will always be in *VHDL*, and `user_logic` module will be in the language you select in step I-13. This tutorial will present you with solutions in both *VHDL* and *Verilog*.

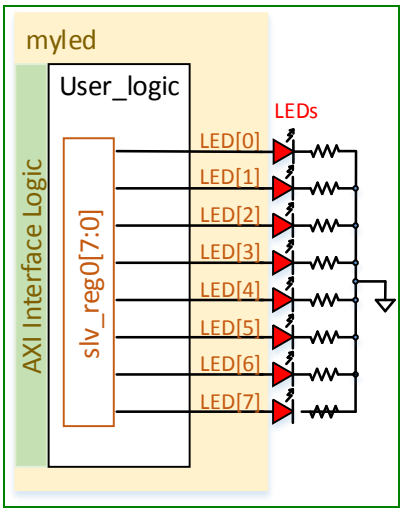


Figure 19. myled IP Block Diagram

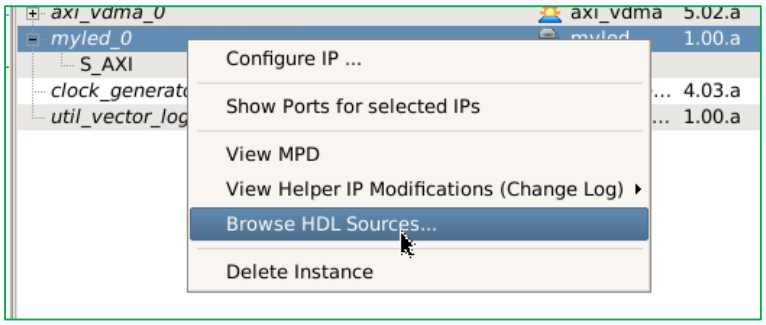


Figure 20. Open HDL Source File of myled

I-17 (For *VHDL* Users) Right click on **myled_0** and click **Browse HDL Sources** (as shown in Figure 20). In the pop-up window locate source file `user_logic.vhd` under `xps_proj/pcores/myled_v1_00_a/hdl/vhdl/`. In the declaration of the `user_logic` entity, add a user port named `LED` and define it as `output, std_logic_vector(7 downto 0)`. In the logic implementation, connect the lower 8 bits of `slv_reg0` to `LED`, as shown in Example 3 - *VHDL*.

I-17 (For *Verilog* Users) Right click on **myled_0** and click **Browse HDL Sources** (as shown in Figure 20). In the pop-up window locate source file `user_logic.v` under `xps_proj/pcores/myled_v1_00_a/hdl/verilog/`. In the declaration of the `user_logic` module, add a user port named `LED` and define it as `output [7:0]`. In the logic implementation, connect the lower 8 bits of `slv_reg0` to `LED`, as shown in Example 3 - *Verilog*.

Example 3 – *VHDL*.

```
 84 entity user_logic is
 85   generic
 86   (
       ...
 96   );
 97   port
 98   (
 99     -- ADD USER PORTS BELOW THIS LINE ------------------
100     --USER ports added here
101     LED                            : out std_logic_vector(7 downto 0);
102     -- ADD USER PORTS ABOVE THIS LINE ------------------
       ...
117   );
       ...
147   --USER signal declarations added here, as needed for user logic
148    LED <= slv_reg0(7 downto 0);
```

Example 3 – *Verilog*.

```
 54 module user_logic
 55 (
 56     // -- ADD USER PORTS BELOW THIS LINE ------------------
 57     // --USER ports added here
 58     LED,
 59     // -- ADD USER PORTS ABOVE THIS LINE ------------------
      ...
 74 );
    ...
 86 // -- ADD USER PORTS BELOW THIS LINE -----------------
 87 // --USER ports added here
 88 output     [7 : 0]                          LED;
 89 // -- ADD USER PORTS ABOVE THIS LINE -----------------
    ...
120   // USER logic implementation added here
121   LED = slv_reg0[7:0];
122
```

I-18 (Both *Verilog* & *VHDL*) Right click on **myled_0** and click **Browse HDL Sources** (as shown in Figure 20). In the pop-up window locate source file `myled.vhd` under `xps_proj/pcores/myled_v1_00_a/hdl/vhdl/`. In the declaration of the myled entity, add a user port named `LED` and define it as `output, std_logic_vector(7 downto 0)`. Connect `LED` of `user_logic` to `LED` of `myled`, as shown in **Example 4**.

Example 4.

```
114 entity myled is
115   generic
116   (
       ...
136   );
137   port
138   (
139     -- ADD USER PORTS BELOW THIS LINE ------------------
140     --USER ports added here
141     LED                           : out std_logic_vector(7 downto 0);
142     -- ADD USER PORTS ABOVE THIS LINE ------------------
       ...
166   );
       ...
292   USER_LOGIC_I : entity myled_v1_00_a.user_logic
293     generic map
294     (
       ...
301     )
302     port map
303     (
304       -- MAP USER PORTS BELOW THIS LINE ------------------
305       --USER ports mapped here
306       LED                           => LED,
307       -- MAP USER PORTS ABOVE THIS LINE ------------------
       ...
319     );
```

I-19 Right click on **myled_0** and click **View MPD**, as shown in Figure 21. In the MPD (Microprocessor Peripheral Definition), add a port declaration for LED (as shown in **Example 5**).

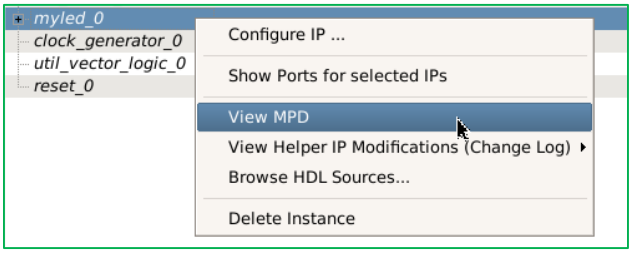


Figure 21. Open MPD of myled

Example 5.

```
    ...
38 ## Ports
39 PORT LED = "", DIR = O, VEC = [7:0]
40 PORT S_AXI_ACLK = "", DIR = I, SIGIS = CLK, BUS = S_AXI
    ...
```

I-20 Click **Project->Rescan User Repositories** to make port LED show up in the **Ports** tab (as shown in Figure 22). Switch to the **Ports** tab, expand **myled_0**, and connect **LED** to **External Ports** (as shown in Figure 23). Its default name is `myled_0_LED_pin`.

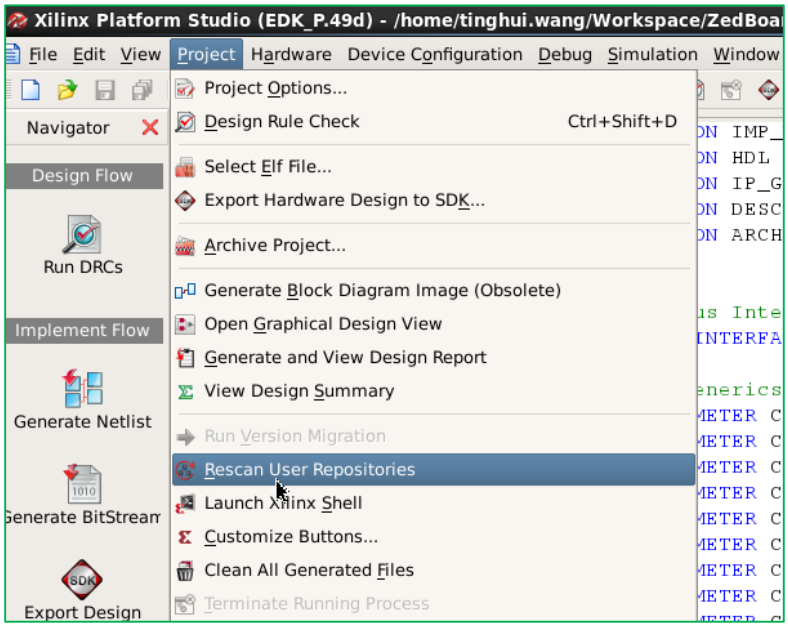


Figure 22. Rescan User Repositories

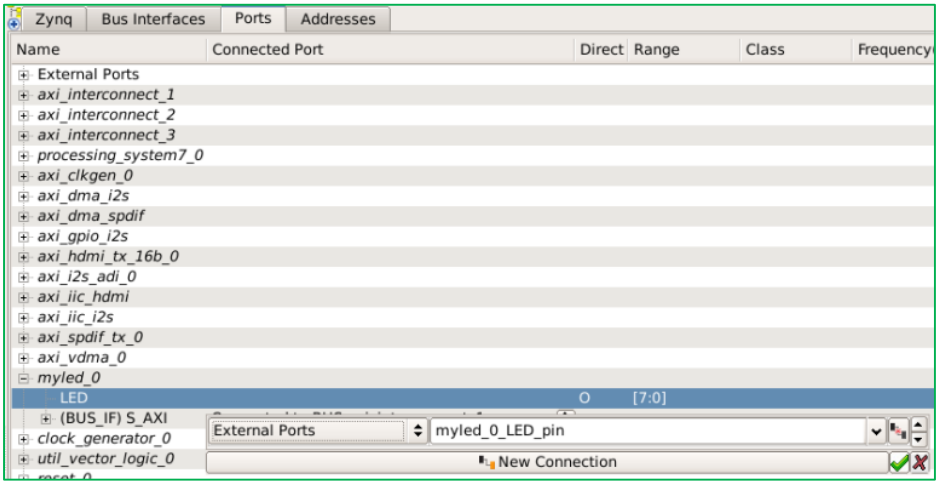


Figure 23. Connect LED to external ports

I-20 The final step is to specify the pin numbers for `myled_0_LED_pin` to physically connect our customized IP core to the on-board LEDs. Double click UCF File: `data/system.ucf` as shown in Figure 24. Change the pin mapping according to Example 6.

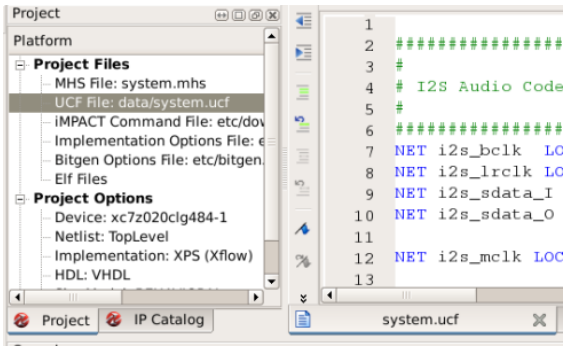


Figure 24. Open System UCF File

Example 6.

```
79
80 ############################
81 #                          #
82 # On-board LED's           #
83 #                          #
84 ############################
85 net myled_0_LED_pin<0> LOC = T22 | IOSTANDARD = LVCMOS33;    # LD0
86 net myled_0_LED_pin<1> LOC = T21 | IOSTANDARD = LVCMOS33;    # LD1
87 net myled_0_LED_pin<2> LOC = U22 | IOSTANDARD = LVCMOS33;    # LD2
88 net myled_0_LED_pin<3> LOC = U21 | IOSTANDARD = LVCMOS33;    # LD3
89 net myled_0_LED_pin<4> LOC = V22 | IOSTANDARD = LVCMOS33;    # LD4
90 net myled_0_LED_pin<5> LOC = W22 | IOSTANDARD = LVCMOS33;    # LD5
91 net myled_0_LED_pin<6> LOC = U19 | IOSTANDARD = LVCMOS33;    # LD6
92 net myled_0_LED_pin<7> LOC = U14 | IOSTANDARD = LVCMOS33;    # LD7
93
```

Example 6 (Cont.)

```
 94 ############################
 95 #                           #
 96 # On-board Slide Switches   #
 97 #                           #
 98 ############################
 99 net processing_system7_0_GPIO<7>  LOC = F22 | IOSTANDARD = LVCMOS33;    # SW0
100 net processing_system7_0_GPIO<8>  LOC = G22 | IOSTANDARD = LVCMOS33;    # SW1
101 net processing_system7_0_GPIO<9>  LOC = H22 | IOSTANDARD = LVCMOS33;    # SW2
102 net processing_system7_0_GPIO<10> LOC = F21 | IOSTANDARD = LVCMOS33;    # SW3
103 net processing_system7_0_GPIO<11> LOC = H19 | IOSTANDARD = LVCMOS33;    # SW4
104 net processing_system7_0_GPIO<12> LOC = H18 | IOSTANDARD = LVCMOS33;    # SW5
105 net processing_system7_0_GPIO<13> LOC = H17 | IOSTANDARD = LVCMOS33;    # SW6
106 net processing_system7_0_GPIO<14> LOC = M15 | IOSTANDARD = LVCMOS33;    # SW7
107
108 ############################
109 #                           #
110 # On-board Left, Right,     #
111 # Up, Down, and Select      #
112 # Pushbuttons               #
113 #                           #
114 ############################
115 net processing_system7_0_GPIO<15> LOC = N15 | IOSTANDARD = LVCMOS33;    # BTNL
116 net processing_system7_0_GPIO<16> LOC = R18 | IOSTANDARD = LVCMOS33;    # BTNR
117 net processing_system7_0_GPIO<17> LOC = T18 | IOSTANDARD = LVCMOS33;    # BTNU
118 net processing_system7_0_GPIO<18> LOC = R16 | IOSTANDARD = LVCMOS33;    # BTND
119 net processing_system7_0_GPIO<19> LOC = P16 | IOSTANDARD = LVCMOS33;    # BTNS
120
121 ############################
122 #                           #
123 # Pmod JA                   #
124 #                           #
125 ############################
126 net processing_system7_0_GPIO<20> LOC = Y11  | IOSTANDARD = LVCMOS33;   # JA1
127 net processing_system7_0_GPIO<21> LOC = AA11 | IOSTANDARD = LVCMOS33;   # JA2
128 net processing_system7_0_GPIO<22> LOC = Y10  | IOSTANDARD = LVCMOS33;   # JA3
129 net processing_system7_0_GPIO<23> LOC = AA9  | IOSTANDARD = LVCMOS33;   # JA4
130 net processing_system7_0_GPIO<24> LOC = AB11 | IOSTANDARD = LVCMOS33;   # JA7
131 net processing_system7_0_GPIO<25> LOC = AB10 | IOSTANDARD = LVCMOS33;   # JA8
132 net processing_system7_0_GPIO<26> LOC = AB9  | IOSTANDARD = LVCMOS33;   # JA9
133 net processing_system7_0_GPIO<27> LOC = AA8  | IOSTANDARD = LVCMOS33;   # JA10
134
135 ############################
136 #                           #
137 # Pmod JB                   #
138 #                           #
139 ############################
140 net processing_system7_0_GPIO<28> LOC = W12 | IOSTANDARD = LVCMOS33;    # JB1
141 net processing_system7_0_GPIO<29> LOC = W11 | IOSTANDARD = LVCMOS33;    # JB2
142 net processing_system7_0_GPIO<30> LOC = V10 | IOSTANDARD = LVCMOS33;    # JB3
143 net processing_system7_0_GPIO<31> LOC = W8  | IOSTANDARD = LVCMOS33;    # JB4
144 net processing_system7_0_GPIO<32> LOC = V12 | IOSTANDARD = LVCMOS33;    # JB7
145 net processing_system7_0_GPIO<33> LOC = W10 | IOSTANDARD = LVCMOS33;    # JB8
146 net processing_system7_0_GPIO<34> LOC = V9  | IOSTANDARD = LVCMOS33;    # JB9
147 net processing_system7_0_GPIO<35> LOC = V8  | IOSTANDARD = LVCMOS33;    # JB10
```

Example 6 (Cont.)

```
148
149 ############################
150 #                          #
151 # Pmod JC                  #
152 #                          #
153 ############################
154 net processing_system7_0_GPIO<36> LOC = AB7 | IOSTANDARD = LVCMOS33;  # JC1_P (JC1)
155 net processing_system7_0_GPIO<37> LOC = AB6 | IOSTANDARD = LVCMOS33;  # JC1_N (JC2)
156 net processing_system7_0_GPIO<38> LOC = Y4  | IOSTANDARD = LVCMOS33;  # JC2_P (JC3)
157 net processing_system7_0_GPIO<39> LOC = AA4 | IOSTANDARD = LVCMOS33;  # JC2_N (JC4)
158 net processing_system7_0_GPIO<40> LOC = R6  | IOSTANDARD = LVCMOS33;  # JC3_P (JC7)
159 net processing_system7_0_GPIO<41> LOC = T6  | IOSTANDARD = LVCMOS33;  # JC3_N (JC8)
160 net processing_system7_0_GPIO<42> LOC = T4  | IOSTANDARD = LVCMOS33;  # JC4_P (JC9)
161 net processing_system7_0_GPIO<43> LOC = U4  | IOSTANDARD = LVCMOS33;  # JC4_N (JC10)
162
163 ############################
164 #                          #
165 # Pmod JD                  #
166 #                          #
167 ############################
168 net processing_system7_0_GPIO<44> LOC = V7  | IOSTANDARD = LVCMOS33;  # JD1_P (JD1)
169 net processing_system7_0_GPIO<45> LOC = W7  | IOSTANDARD = LVCMOS33;  # JD1_N (JD2)
170 net processing_system7_0_GPIO<46> LOC = V5  | IOSTANDARD = LVCMOS33;  # JD2_P (JD3)
171 net processing_system7_0_GPIO<47> LOC = V4  | IOSTANDARD = LVCMOS33;  # JD2_N (JD4)
172 net processing_system7_0_GPIO<48> LOC = W6  | IOSTANDARD = LVCMOS33;  # JD3_P (JD7)
173 net processing_system7_0_GPIO<49> LOC = W5  | IOSTANDARD = LVCMOS33;  # JD3_N (JD8)
174 net processing_system7_0_GPIO<50> LOC = U6  | IOSTANDARD = LVCMOS33;  # JD4_P (JD9)
175 net processing_system7_0_GPIO<51> LOC = U5  | IOSTANDARD = LVCMOS33;  # JD4_N (JD10)
```

I-21 Regenerate the bit stream for the hardware design by clicking on **Hardware -> Generate Bitstream**, as shown in Figure 25.

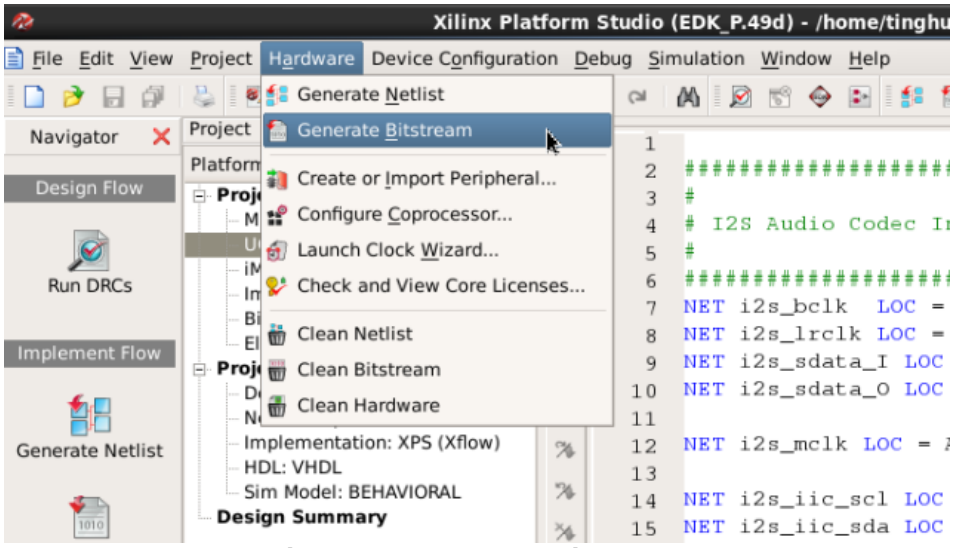


Figure 25. Generate Bitstream

Section II: Compile U-Boot (Optional)

Prerequisites

➢**Xilinx ISE DS 14.4 (WebPack)**
available at Xilinx Website Download Page

➢**ZedBoard Linux Hardware Design**
available at Digilent Website ZedBoard Page

Instructions

II-1 Get the source code for U-Boot from the Digilent git repository. There are two ways to retrieve the source code:

a. Using *git* command: If you have git installed in your distribution, you can clone the repository to your computer by command `git clone https://github.com/Digilent/u-boot-digilent`. The whole Git Repository is around 55MB, as shown in Example 7.

Example 7.

```
[tinghui.wang@DIGILENT_LINUX Tutorial]$ git clone https://github.com/Digilent/u-boot-digilent
Initialized empty Git repository in
/home/tinghui.wang/Workspace/ZedBoard/Project/14_4/Tutorial/u-boot-digilent/.git/
remote: Counting objects: 190139, done.
remote: Compressing objects: 100% (36339/36339), done.
remote: Total 190139 (delta 153023), reused 188409 (delta 151293)
Receiving objects: 100% (190139/190139), 54.94 MiB | 158 KiB/s, done.
Resolving deltas: 100% (153023/153023), done.
[tinghui.wang@DIGILENT_LINUX Tutorial]$
```

b. Download a compressed package: If you only want to use u-boot once and do not want to track the updates, you can also download a compressed package from github.com: https://github.com/Digilent/u-boot-digilent. Click **Tags** on the top right corner of the page, and the most recent tag is **v2012.04-digilent-13.01**.

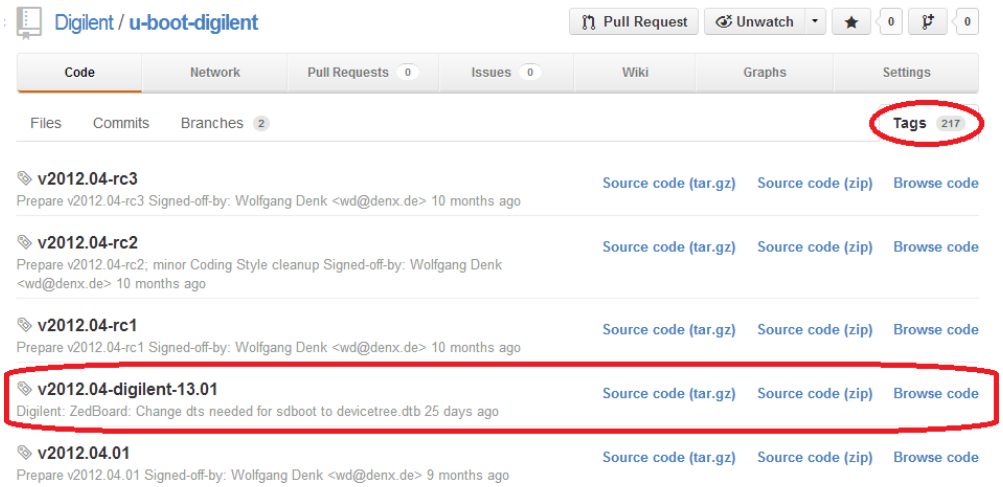


Figure 26. Download Source code from github website

If you downloaded the tar.gz, you can decompress it using command
`tar zxvf u-boot-digilent-2012.04-digilent-13.01.tar.gz`

If you downloaded the zip file, you can decompress it using command
`unzip u-boot-digilent-2012.04-digilent-13.01.zip`

II-2 In this part, we are going to set a different MAC address and static IP address so that the board can work in local networks. All the settings for ZedBoard are in the file located at `include/configs/zynq_zed.h`. We will edit it using **vim** (as shown in Example 8), and change the MAC address to `00:0a:35:00:01:45`, IP address to `192.168.10.250`, and gateway IP to `192.168.10.1`, (as shown in Example 9). Save the file using command **:wq**.

Example 8.

```
[tinghui.wang@DIGILENT_LINUX Tutorial]$ cd u-boot-digilent/
[tinghui.wang@DIGILENT_LINUX u-boot-digilent]$ vim include/configs/zynq_zed.h
```

Example 9.

```
30 /* Default environment */
31 #define CONFIG_IPADDR   192.168.10.250
32 #define CONFIG_SERVERIP 192.168.10.1
33
34 #undef CONFIG_ZYNQ_XIL_LQSPI
   ...
40 #undef CONFIG_EXTRA_ENV_SETTINGS
41 #define CONFIG_EXTRA_ENV_SETTINGS    \
42     "ethaddr=00:0a:35:00:01:45\0"    \
43     "kernel_size=0x140000\0"     \
44     "ramdisk_size=0x200000\0"    \
```

II-3 To compile U-Boot, we need cross-compile tools which are provided by **Xilinx ISE 14.4**. Those tools have a prefix `arm-xilinx-linux-gnueabi-` to the standard names for the **GCC** tool chain. In order to use the cross-platform compilers, please make sure Xilinx ISE 14.4 settings have been sourced. If not, please refer to step **I-2**. To configure and build U-Boot for ZedBoard, follow Example 10.

Example 10.

```
[tinghui.wang@DIGILENT_LINUX u-boot-digilent]$ make CROSS_COMPILE=arm-xilinx-linux-gnueabi-
zynq_zed_config
Configuring for zynq_zed board...
[tinghui.wang@DIGILENT_LINUX u-boot-digilent]$ make CROSS_COMPILE=arm-xilinx-linux-gnueabi-
Generating include/autoconf.mk
Generating include/autoconf.mk.dep
arm-xilinx-linux-gnueabi-gcc -DDO_DEPS_ONLY \
...
make -C examples/api all
make[1]: Entering directory `/home/tinghui.wang/Workspace/ZedBoard/Project/14_4/Tutorial/u-
boot-digilent/examples/api'
make[1]: Nothing to be done for `all'.
make[1]: Leaving directory `/home/tinghui.wang/Workspace/ZedBoard/Project/14_4/Tutorial/u-
boot-digilent/examples/api'
[tinghui.wang@DIGILENT_LINUX u-boot-digilent]$
```

II-4 After the compilation, the **ELF** (**E**xecutable and **L**inkable **F**ile) generated is named `u-boot`. We need to add a `.elf` extension to the file name so that **Xilinx SDK** can read the file layout and generate `BOOT.BIN`. In this tutorial, we are going to move the `u-boot.elf` to `boot_image` folder and substitute the `u-boot.elf` that comes along with ZedBoard Embedded Linux Design Package, as shown in Example 11.

Example 11.

```
[tinghui.wang@DIGILENT_LINUX u-boot-digilent]$ cp u-boot
../ZedBoard_Linux_Design/boot_image/u-boot.elf
[tinghui.wang@DIGILENT_LINUX u-boot-digilent]$
```

Section III: Generate BOOT.BIN

Prerequisites

- **Xilinx ISE DS 14.4 (WebPack)**
  available at Xilinx Website Download Page

- *ZedBoard Linux Hardware Design*
  available at Digilent Website ZedBoard Page

- *Finished Hardware Design from **Section I** & u-boot.elf from **Section II** (Section II optional)*

Instructions

III-1 Export the hardware design (after step I-21) to Xilinx SDK by clicking on **Project -> Export Hardware Design to SDK…**, as shown in Figure 27. In the pop-up window, click **Export and Launch SDK**, as shown in Figure 28.

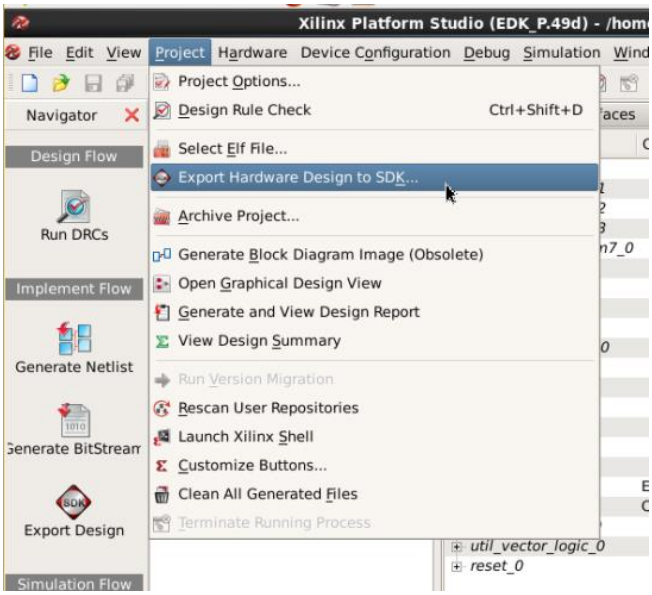


Figure 27. Export Hardware Design to SDK

Figure 28. Export and Launch SDK

III-2 Set Workspace to `ZedBoard_Linux_Design/hw/xps_proj/SDK/SDK_Export` and click **OK**, as shown in Figure 29.

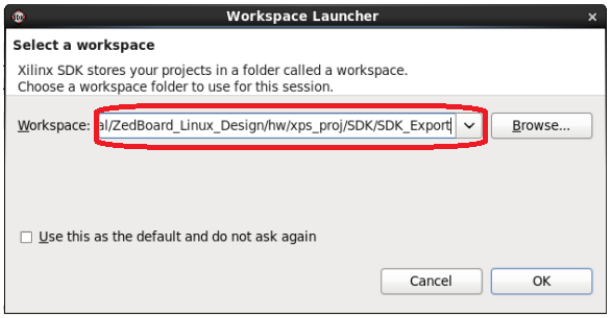


Figure 29. Set SDK Workspace Path

III-3 After SDK launches, the hardware platform project is already present in Project Explorer on the left of the SDK main window, as shown in Figure 30. We now need to create a First Stage Bootloader (FSBL). Click **File->New->Project…**, as shown in Figure 31.

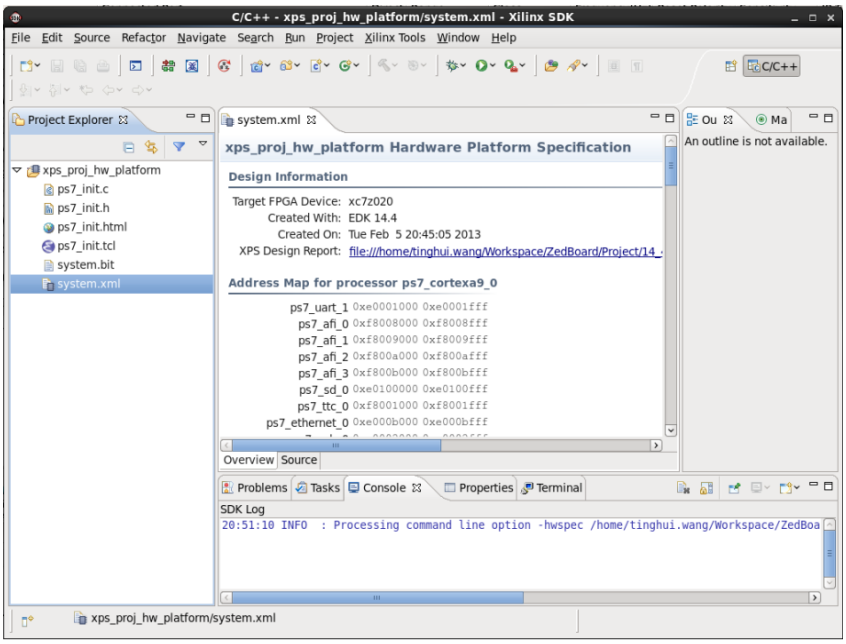


Figure 30. Xilinx SDK Window

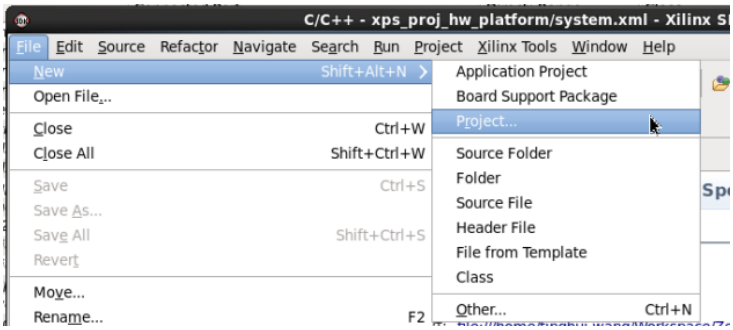


Figure 31. Create New Project in SDK

III-4 In the New Project window, select **Xilinx->Application Project**, and then Click **Next** (Figure 32).

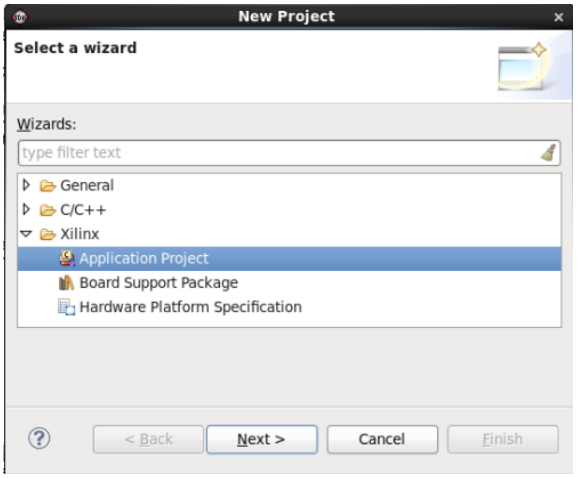


Figure 32. Select Application Project Wizard

III-5 We will name the project FSBL. Select **xps_proj_hw_platform** for **Target Hardware** because it is the hardware project we just exported. Select **standalone** for **OS Platform**. Click **Next**. (as shown in Figure 33).

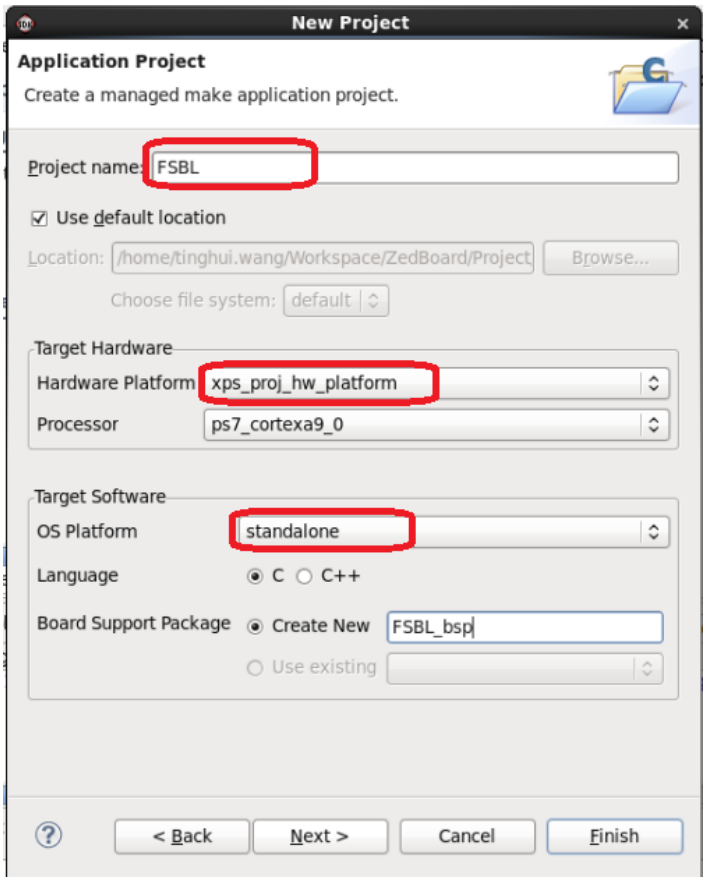


Figure 33. New Application Project

III-6 Select **Zynq FSBL** as template, and click Finish (as shown in Figure 34).

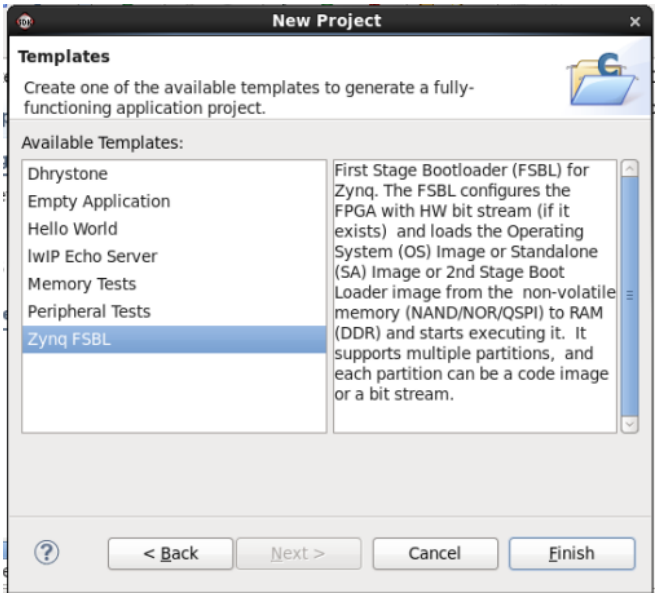


Figure 34. Select Zynq FSBL as Template

III-7 For the ZedBoard, we need to reset the USB PHY chip by toggling the USB-Reset pin in the FSBL. You can swap the `main.c` file in the FSBL project with the `main.c` under `sw/zynq_fsbl/src` in the ZedBoard Linux Design Package. Alternatively, you can add the following code in Example 12 to `main.c` of the FSBL project.

Example 12.

```
470     FsblMeasurePerfTime(tCur,tEnd);
471 #endif
472
473     /* Reset the USB */
474     {
475         fsbl_printf(DEBUG_GENERAL, "Reset USB...\r\n");
476
477         /* Set data dir */
478         *(unsigned int *)0xe000a284 = 0x00000001;
479
480         /* Set OEN */
481         *(unsigned int *)0xe000a288 = 0x00000001;
482         Xil_DCacheFlush();
483         /* For REVB Set data value low for reset, then back high */
484 #ifdef ZED_REV_A
485         *(unsigned int *)0xe000a048 = 0x00000001;
486         Xil_DCacheFlush();
487         *(unsigned int *)0xe000a048 = 0x00000000;
488         Xil_DCacheFlush();
489 #else
490         *(unsigned int *)0xe000a048 = 0x00000000;
491         Xil_DCacheFlush();
492         *(unsigned int *)0xe000a048 = 0x00000001;
493         Xil_DCacheFlush();
494 #endif
495     }
```

III-8 After you have saved the changes to `main.c`, the project will rebuild itself automatically. If it does not rebuild, Click **Project->Clean** to clean the project files, and **Project->Build All** to rebuild all the projects. The compiled ELF file is located in `ZedBoard_Linux_Design/hw/xps_proj/SDK/SDK_Export/FSBL/Debug/FSBL.elf`

III-9 Now, we have all the files ready to create `BOOT.BIN`. Click **Xilinx Tools -> Create Zynq Boot Image**, as shown in Figure 35.

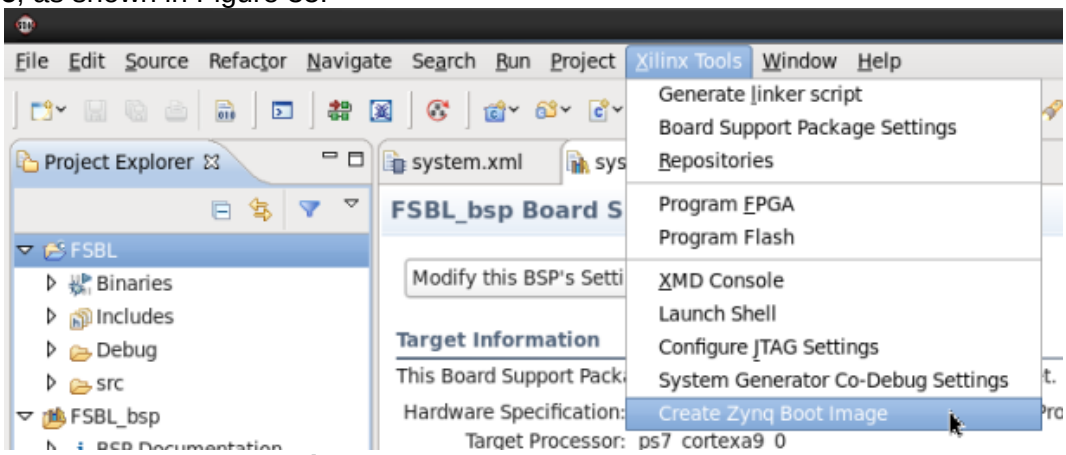


Figure 35. Create Zynq Boot Image

III-10 In the Create Zynq Boot Image window (as shown in Figure 36), Click **Browse** to set the path for **FSBL elf**. Click **Add** to add the `system.bit` file found at `ZedBoard_Linux_Design/hw/xps_proj/SDK/SDK_Export/xps_proj_hw_platform/`.Click **Add** to add the `u-boot.elf` file found at `ZedBoard_Linux_Design/boot_image/`. *It is very important that the 3 files are added in this order,* or else the FSBL will not work properly (the proper order can be seen in Figure 36). In this tutorial, the `boot_image` folder is set as output folder for the BIN file. Click **Create Image**.

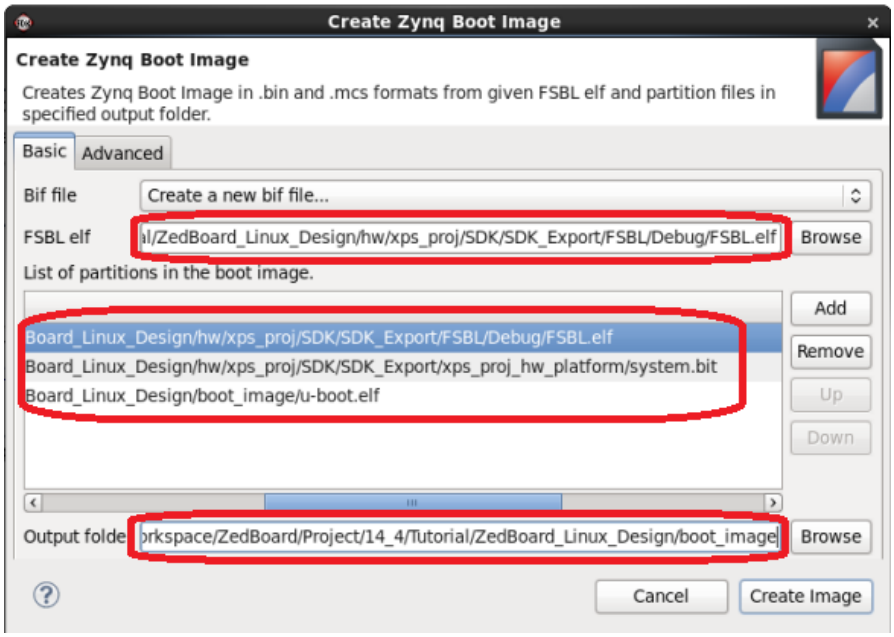


Figure 36. Create Zynq Boot Image Configuration

III-11 The created BIN file was named u-boot.bin. We need to rename it to BOOT.BIN (all in capital letters) so that ZedBoard can find and load it after power up.

Section IV: Compile Linux Kernel

Prerequisites

➢**Xilinx ISE DS 14.4 (WebPack)**
available at Xilinx Website Download Page

➢*ZedBoard Linux Hardware Design*
available at Digilent Website ZedBoard Page

Instructions

IV-1 Get the Linux kernel source code from Digilent git repository. There are two ways to retrieve the source code:

a. Using *git* command: If you have git installed in your distribution, you can clone the repository to your computer by command `git clone https://github.com/Digilent/linux-digilent`. The whole Git Repository is around 550MB, as shown in Example 13.

Example 13.

```
[tinghui.wang@DIGILENT_LINUX Tutorial]$ git clone https://github.com/Digilent/linux-digilent
Initialized empty Git repository in
/home/tinghui.wang/Workspace/ZedBoard/Project/14_4/Tutorial/linux-digilent/.git/
remote: Counting objects: 2640848, done.
remote: Compressing objects: 100% (425292/425292), done.
remote: Total 2640848 (delta 2210020), reused 2620443 (delta 2189623)
Receiving objects: 100% (2640848/2640848), 565.52 MiB | 641 KiB/s, done.
Resolving deltas: 100% (2210020/2210020), done.
Checking out files: 100% (40001/40001), done.
[tinghui.wang@DIGILENT_LINUX Tutorial]$
```

b. Download a compressed package: If you only want to use u-boot once and do not want to track the updates, you can also download a compressed package from github.com: https://github.com/Digilent/linux-digilent. Click **Tags** on the top right corner of the page.The most recent tag is **v3.6-digilent-13.01**.

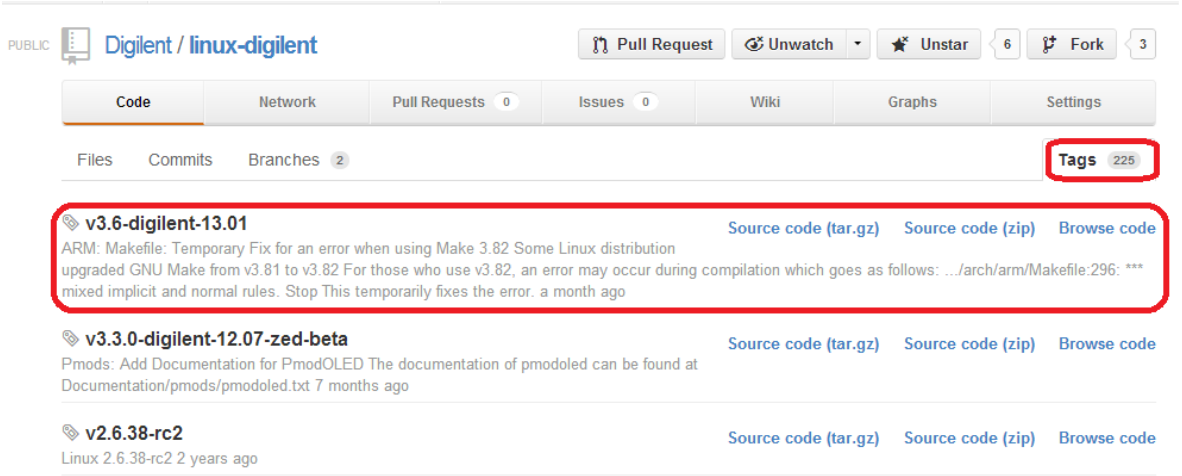


Figure 37. Download Source code from github website

If you downloaded the tar.gz, you can decompress it using command
`tar zxvf linux-digilent-v3.6-digilent-13.01.tar.gz`

If you downloaded the zip file, you can decompress it using command
`unzip linux-digilent-v3.6-digilent-13.01.zip`

IV-2 We will start to configure the kernel with the default configuration for ZedBoard. The configuration is located at `arch/arm/configs/digilent_zed_defconfig`. To use the default configuration, you can follow Example 14.

Example 14.

```
[tinghui.wang@DIGILENT_LINUX Tutorial]$ cd linux-digilent/
[tinghui.wang@DIGILENT_LINUX linux-digilent]$ make ARCH=arm CROSS_COMPILE=arm-xilinx-linux-
gnueabi- digilent_zed_defconfig
  HOSTCC  scripts/basic/fixdep
  HOSTCC  scripts/kconfig/conf.o
  SHIPPED scripts/kconfig/zconf.tab.c
  SHIPPED scripts/kconfig/zconf.lex.c
  SHIPPED scripts/kconfig/zconf.hash.c
  HOSTCC  scripts/kconfig/zconf.tab.o
  HOSTLD  scripts/kconfig/conf
#
# configuration written to .config
#
[tinghui.wang@DIGILENT_LINUX linux-digilent]$
```

IV-3 We will change the configuration for the PmodOLED driver changing it from a built-in driver to a loadable kernel module. To do this, we will start the configuration menu for the Linux kernel by following Example 15. The configuration screen will show up in your terminal as Figure 37.

Example 15.

```
[tinghui.wang@DIGILENT_LINUX linux-digilent]$ make ARCH=arm CROSS_COMPILE=arm-xilinx-linux-
gnueabi- menuconfig
```

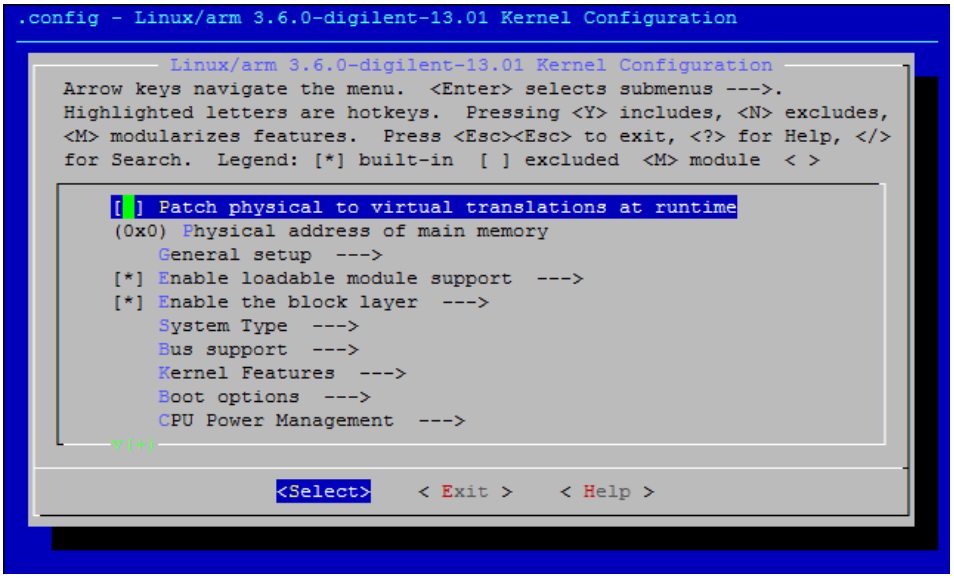


Figure 37. Linux Kernel Configuration Menu

IV-4 Browse to Device Driver-> PMOD Support -> PmodOLED1, press M to modularize the feature, as shown in Figure 38, 39, and 40.

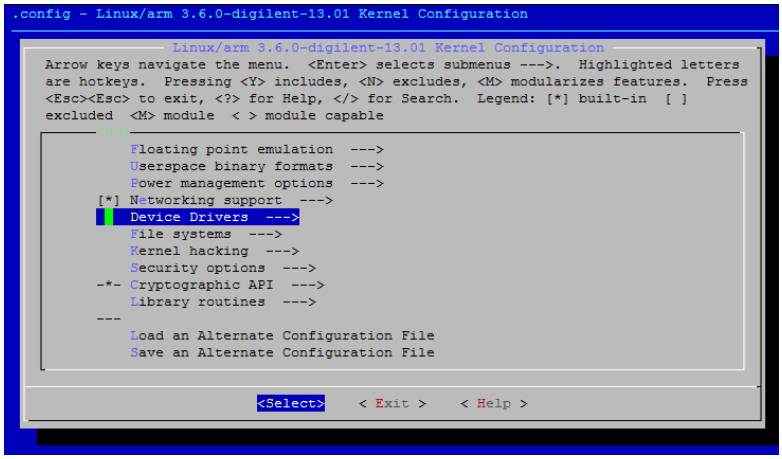


Figure 38. Browse to Device Drivers

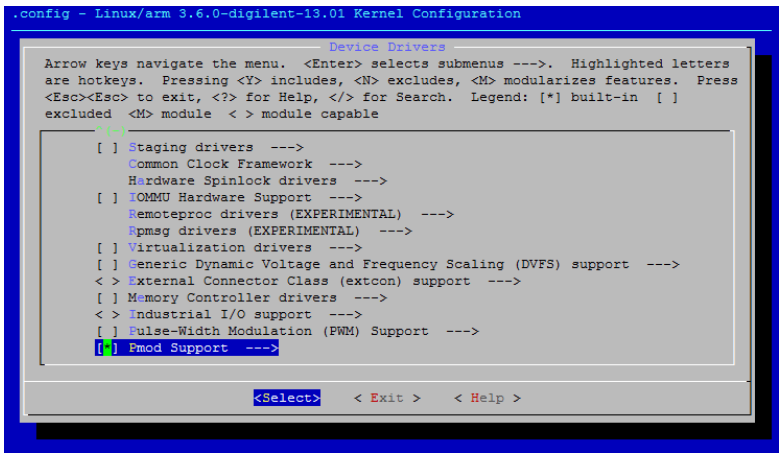


Figure 39. Browse to Pmod Support

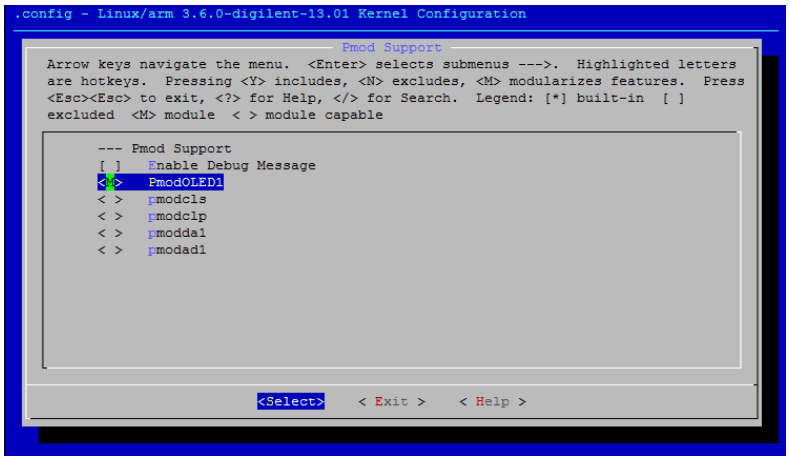


Figure 40. Modularize PmodOLED1 Feature

IV-5 Move the cursor to Exit to exit the Linux Kernel Configuration menu, as shown in Figure 41. Choose YES to save the new configuration, as shown in Figure 42.

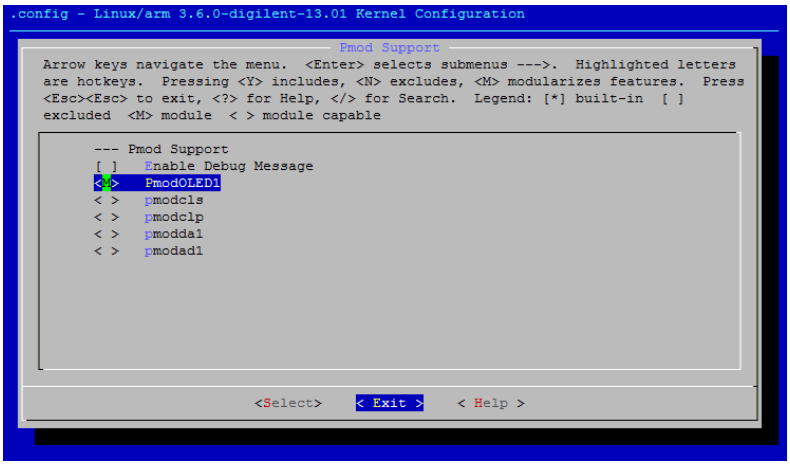


Figure 41. Exit Linux Kernel Configuration Menu

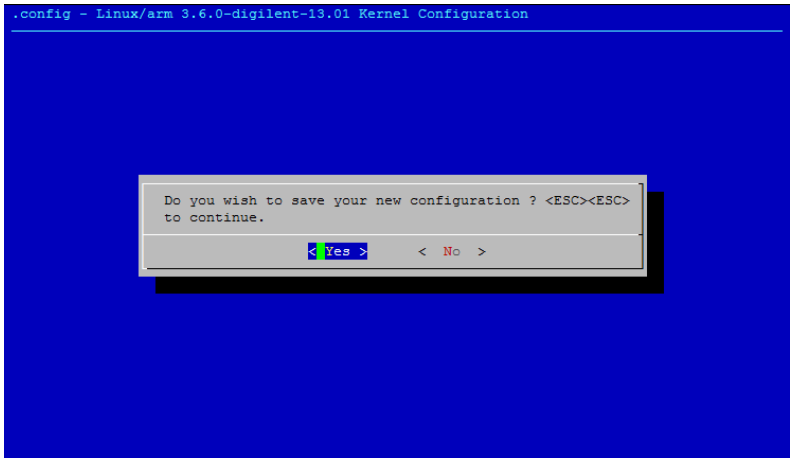


Figure 42. Chose Yes to save the new Linux Kernel Configuration

IV-6 Follow Example 16 to compile the Linux Kernel.

Example 16.

```
[tinghui.wang@DIGILENT_LINUX linux-digilent]$ make ARCH=arm CROSS_COMPILE=arm-xilinx-linux-
gnueabi-
scripts/kconfig/conf --silentoldconfig Kconfig
  WRAP    arch/arm/include/generated/asm/auxvec.h
  WRAP    arch/arm/include/generated/asm/bitsperlong.h
  WRAP    arch/arm/include/generated/asm/cputime.h
  WRAP    arch/arm/include/generated/asm/emergency-restart.h
...
  GEN     .version
  CHK     include/generated/compile.h
  UPD     include/generated/compile.h
  CC      init/version.o
  LD      init/built-in.o
  KSYM    .tmp_kallsyms1.o
  KSYM    .tmp_kallsyms2.o
  LD      vmlinux
```

Example 16 (Cont.).

```
  SYSMAP  System.map
  OBJCOPY arch/arm/boot/Image
  Kernel: arch/arm/boot/Image is ready
  AS      arch/arm/boot/compressed/head.o
  GZIP    arch/arm/boot/compressed/piggy.gzip
  AS      arch/arm/boot/compressed/piggy.gzip.o
  CC      arch/arm/boot/compressed/misc.o
  CC      arch/arm/boot/compressed/decompress.o
  CC      arch/arm/boot/compressed/string.o
  SHIPPED arch/arm/boot/compressed/lib1funcs.S
  AS      arch/arm/boot/compressed/lib1funcs.o
  SHIPPED arch/arm/boot/compressed/ashldi3.S
  AS      arch/arm/boot/compressed/ashldi3.o
  LD      arch/arm/boot/compressed/vmlinux
  OBJCOPY arch/arm/boot/zImage
  Kernel: arch/arm/boot/zImage is ready
  Building modules, stage 2.
  MODPOST 23 modules
...
  CC      drivers/pmods/pmodoled-gpio.mod.o
  LD [M]  drivers/pmods/pmodoled-gpio.ko
...
[tinghui.wang@DIGILENT_LINUX linux-digilent]$
```

IV-7 After the compilation, the kernel image is located at arch/arm/boot/zImage.

Section V: Test Kernel Image with Pre-built File System

Prerequisites

- **Xilinx ISE DS 14.4 (WebPack)**
  available at Xilinx Website Download Page

- *Linux Kernel Source Code*
  available at Digilent github repository: https://github.com/Digilent/linux-digilent

- Pre-built File System Image
  ramdisk Image is available in ZedBoard Linux Reference Design
  linaro File System can be obtained from http://release.linaro.org

- *BOOT.BIN from Section III, zImage from Section IV.*

Instructions

V-1 To boot the Linux Operating System on the ZedBoard, you need BOOT.BIN, a Linux kernel image (zImage), a device tree blob (DTB file), and a file system. BOOT.BIN has been created in Section III and zImage has been compiled in Section IV. We will now compile the DTB file. The default device tree source file is located in the Linux Kernel source at arch/arm/boot/dts/digilent-zed.dt**s.**
RAMDISK: modify the device tree source file according to Example 17.
LINARO FS: use the default device tree source as it is.

Example 17.

```
48      chosen {
49          /* bootargs = "console=ttyPS0,115200 root=/dev/mmcblk0p2 rw earlyprintk
    rootfstype=ext4 rootwait devtmpfs.mount=1"; */
50          bootargs = "console=ttyPS0,115200 root=/dev/ram rw initrd=0x800000,8M
    init=/init earlyprintk rootwait devtmpfs.mount=1";
51          linux,stdout-path = "/axi@0/serial@e0001000";
52      };
```

V-2 Generate DTB file, as shown in Example 18.

Example 18.

```
[tinghui.wang@DIGILENT_LINUX linux-digilent]$ ./scripts/dtc/dtc -I dts -O dtb
-o ../devicetree.dtb arch/arm/boot/dts/digilent-zed.dts
DTC: dts->dtb  on file "arch/arm/boot/dts/digilent-zed.dts"
[tinghui.wang@DIGILENT_LINUX linux-digilent]$
```

V-3 **(RAMDISK)** Copy BOOT.BIN, devicetree.dtb, zImage and ramdisk8M.tar.gz to the first partition of an SD card, as shown in Example 19 – RamDisk.
(LINARO FS) Follow **Formatting the SD Card** in ***Getting Started with Embedded Linux – ZedBoard*** to create the Linaro File System on the second partition of an SD Card. Copy BOOT.BIN, devicetree.dtb, and zImage to the first partition of the SD card, as shown in Example 19 – Linaro.

NOTE: In Example 19, the first partition of the SD card is mounted to /media/ZED_BOOT

Example 19 – RamDisk.

```
[tinghui.wang@DIGILENT_LINUX Tutorial]$ ls
devicetree.dtb  linux-digilent  u-boot-digilent  ZedBoard_Linux_Design
[tinghui.wang@DIGILENT_LINUX Tutorial]$ cp ZedBoard_Linux_Design/boot_image/BOOT.BIN
/media/ZED_BOOT/
[tinghui.wang@DIGILENT_LINUX Tutorial]$ cp ZedBoard_Linux_Design/sd_image/ramdisk8M.image.gz
/BOOT.BIN /media/ZED_BOOT/
[tinghui.wang@DIGILENT_LINUX Tutorial]$ cp ./devicetree.dtb /media/ZED_BOOT/
[tinghui.wang@DIGILENT_LINUX Tutorial]$ cp linux-digilent/arch/arm/boot/zImage
/media/ZED_BOOT/
[tinghui.wang@DIGILENT_LINUX Tutorial]$
```

Example 19 – Linaro.

```
[tinghui.wang@DIGILENT_LINUX Tutorial]$ ls
devicetree.dtb  linux-digilent  u-boot-digilent  ZedBoard_Linux_Design
[tinghui.wang@DIGILENT_LINUX Tutorial]$ cp ZedBoard_Linux_Design/boot_image/BOOT.BIN
/media/ZED_BOOT
[tinghui.wang@DIGILENT_LINUX Tutorial]$ cp ./devicetree.dtb /media/ZED_BOOT
[tinghui.wang@DIGILENT_LINUX Tutorial]$ cp linux-digilent/arch/arm/boot/zImage
/media/ZED_BOOT
[tinghui.wang@DIGILENT_LINUX Tutorial]$
```

V-4 Plug the SD Card into the ZedBoard. To boot from SD card, jumpers for MIO2, MIO3, MIO6 are connected to GND, and jumpers for MIO4 and MIO5 are connected to 3V3. Jumper for JP6 needs to be connected. Connect UART port to PC with micro USB cable and set the UART terminal on PC to 115200 baud rate, 8 data bits, 1 stop bit, no parity, and no flow control. After powering on the board, the console (shown in Figure 43 – RamDisk) should be seen at the UART terminal if you use RamDisk, or you will see the graphic desktop on a monitor that is connected to HDMI port if you use Linaro File system (shown in Figure 43 – Linaro).

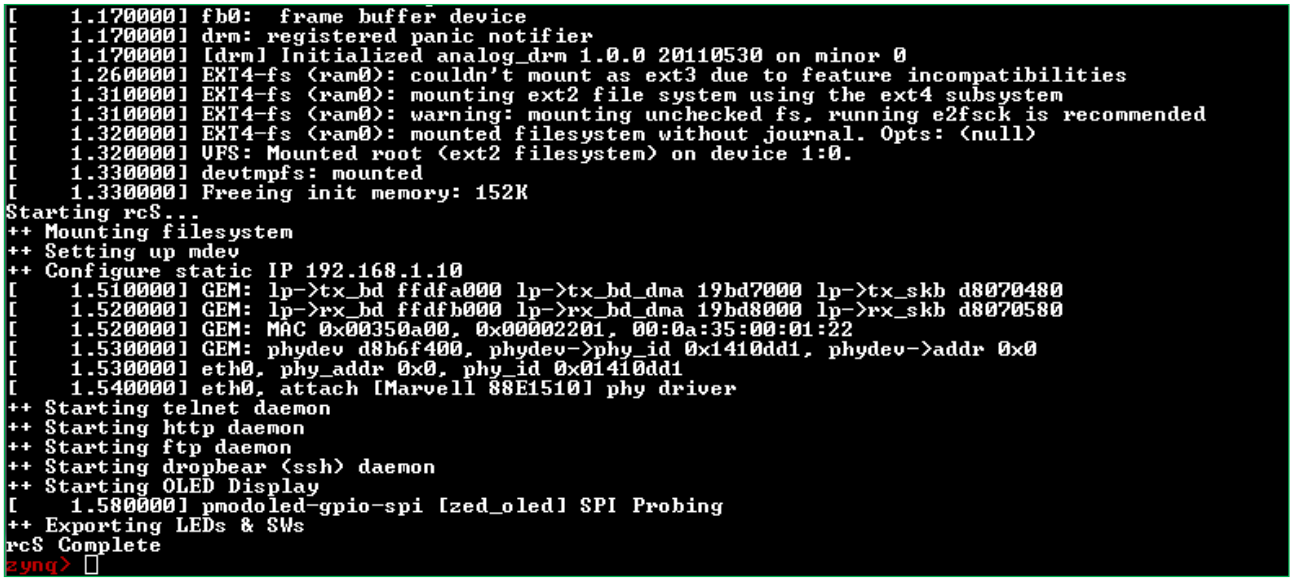


Figure 43 – Ramdisk, UART Console after Boot up

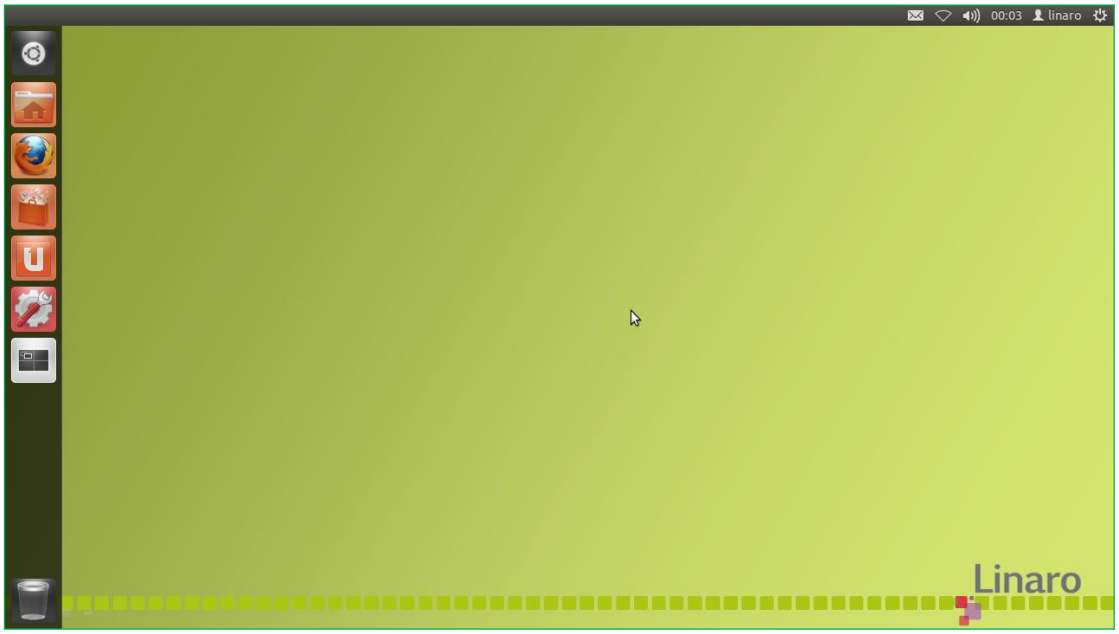


Figure 43 – Linaro Graphical Desktop

Section VI: Modify Device Tree and Compose Kernel Driver

Prerequisites

➢**Xilinx ISE DS 14.4 (WebPack)**
available at Xilinx Website Download Page

➢*Linux Kernel Source Code*
available at Digilent github repository: https://github.com/Digilent/linux-digilent

Instructions

VI-1 Create a directory named drivers in the Tutorial folder, as shown in Example 20. Inside the drivers directory, we will compose the driver for the myled controller.

Example 20.

```
[tinghui.wang@DIGILENT_LINUX Tutorial]$ mkdir drivers
[tinghui.wang@DIGILENT_LINUX Tutorial]$ ls
devicetree.dtb  drivers   inux-digilent  u-boot-digilent  ZedBoard_Linux_Design
[tinghui.wang@DIGILENT_LINUX Tutorial]$
```

VI-2 We need a Makefile so that we can compile the driver. The Makefile is created in Example 21.

Example 21 – Command Line.

```
[tinghui.wang@DIGILENT_LINUX Tutorial]$ cd drivers
[tinghui.wang@DIGILENT_LINUX drivers]$ vim Makefile
```

Example 21 – Makefile.

```
1 obj-m := myled.o
2
3 all:
4     make -C ../linux-digilent/ M=$(PWD) modules
5
6 clean:
7     make -C ../linux-digilent/ M=$(PWD) clean
```

VI-3 We will start with a simple driver that creates a file named myled under the Linux /proc file system. The status of the on-board LEDs can be changed by writing a number to the file. The driver is coded in Example 22.

Example 22 – Command Line

```
[tinghui.wang@DIGILENT_LINUX drivers]$ vim myled.c
```

Example 22 – myled.c

```
1 #include <linux/kernel.h>
2 #include <linux/module.h>
3 #include <asm/uaccess.h>    /* Needed for copy_from_user */
4 #include <asm/io.h>         /* Needed for IO Read/Write Functions */
5 #include <linux/proc_fs.h>  /* Needed for Proc File System Functions */
6 #include <linux/seq_file.h> /* Needed for Sequence File Operations */
```

Example 22 – myled.c (Cont.)

```
 7 #include <linux/platform_device.h>  /* Needed for Platform Driver Functions */
 8
 9 /* Define Driver Name */
10 #define DRIVER_NAME "myled"
11
12 unsigned long *base_addr;   /* Vitual Base Address */
13 struct resource *res;       /* Device Resource Structure */
14 unsigned long remap_size;   /* Device Memory Size */
15
16 /* Write operation for /proc/myled
17  * ----------------------------------
18  *  When user cat a string to /proc/myled file, the string will be stored in
19  *  const char __user *buf. This function will copy the string from user
20  *  space into kernel space, and change it to an unsigned long value.
21  *  It will then write the value to the register of myled controller,
22  *  and turn on the corresponding LEDs eventually.
23  */
24 static ssize_t proc_myled_write(struct file *file, const char __user * buf,
25                 size_t count, loff_t * ppos)
26 {
27     char myled_phrase[16];
28     u32 myled_value;
29
30     if (count < 11) {
31         if (copy_from_user(myled_phrase, buf, count))
32             return -EFAULT;
33
34         myled_phrase[count] = '\0';
35     }
36
37     myled_value = simple_strtoul(myled_phrase, NULL, 0);
38     wmb();
39     iowrite32(myled_value, base_addr);
40     return count;
41 }
42
43 /* Callback function when opening file /proc/myled
44  * -------------------------------------------------
45  *  Read the register value of myled controller, print the value to
46  *  the sequence file struct seq_file *p. In file open operation for /proc/myled
47  *  this callback function will be called first to fill up the seq_file,
48  *  and seq_read function will print whatever in seq_file to the terminal.
49  */
50 static int proc_myled_show(struct seq_file *p, void *v)
51 {
52     u32 myled_value;
53     myled_value = ioread32(base_addr);
54     seq_printf(p, "0x%x", myled_value);
55     return 0;
56 }
57
```

Example 22 – myled.c (Cont.)

```
 58 /* Open function for /proc/myled
 59  * ------------------------------------
 60  *  When user want to read /proc/myled (i.e. cat /proc/myled), the open function
 61  *  will be called first. In the open function, a seq_file will be prepared and the
 62  *  status of myled will be filled into the seq_file by proc_myled_show function.
 63  */
 64 static int proc_myled_open(struct inode *inode, struct file *file)
 65 {
 66     unsigned int size = 16;
 67     char *buf;
 68     struct seq_file *m;
 69     int res;
 70
 71     buf = (char *)kmalloc(size * sizeof(char), GFP_KERNEL);
 72     if (!buf)
 73         return -ENOMEM;
 74
 75     res = single_open(file, proc_myled_show, NULL);
 76
 77     if (!res) {
 78         m = file->private_data;
 79         m->buf = buf;
 80         m->size = size;
 81     } else {
 82         kfree(buf);
 83     }
 84
 85     return res;
 86 }
 87
 88 /* File Operations for /proc/myled */
 89 static const struct file_operations proc_myled_operations = {
 90     .open = proc_myled_open,
 91     .read = seq_read,
 92     .write = proc_myled_write,
 93     .llseek = seq_lseek,
 94     .release = single_release
 95 };
 96
 97 /* Shutdown function for myled
 98  * ------------------------------------
 99  *  Before myled shutdown, turn-off all the leds
100  */
101 static void myled_shutdown(struct platform_device *pdev)
102 {
103     iowrite32(0, base_addr);
104 }
105
```

Example 22 – myled.c (Cont.)

```
106 /* Remove function for myled
107  * ---------------------------------
108  *  When myled module is removed, turn off all the leds first,
109  *  release virtual address and the memory region requested.
110  */
111 static int myled_remove(struct platform_device *pdev)
112 {
113     myled_shutdown(pdev);
114 
115     /* Remove /proc/myled entry */
116     remove_proc_entry(DRIVER_NAME, NULL);
117 
118     /* Release mapped virtual address */
119     iounmap(base_addr);
120 
121     /* Release the region */
122     release_mem_region(res->start, remap_size);
123 
124     return 0;
125 }
126 
127 /* Device Probe function for myled
128  * ------------------------------------
129  *  Get the resource structure from the information in device tree.
130  *  request the memory regioon needed for the controller, and map it into
131  *  kernel virtual memory space. Create an entry under /proc file system
132  *  and register file operations for that entry.
133  */
134 static int __devinit myled_probe(struct platform_device *pdev)
135 {
136     struct proc_dir_entry *myled_proc_entry;
137     int ret = 0;
138 
139     res = platform_get_resource(pdev, IORESOURCE_MEM, 0);
140     if (!res) {
141         dev_err(&pdev->dev, "No memory resource\n");
142         return -ENODEV;
143     }
144 
145     remap_size = res->end - res->start + 1;
146     if (!request_mem_region(res->start, remap_size, pdev->name)) {
147         dev_err(&pdev->dev, "Cannot request IO\n");
148         return -ENXIO;
149     }
150 
151     base_addr = ioremap(res->start, remap_size);
152     if (base_addr == NULL) {
153         dev_err(&pdev->dev, "Couldn't ioremap memory at 0x%08lx\n",
154             (unsigned long)res->start);
155         ret = -ENOMEM;
156         goto err_release_region;
157     }
158 
```

Example 22 – myled.c (Cont.)

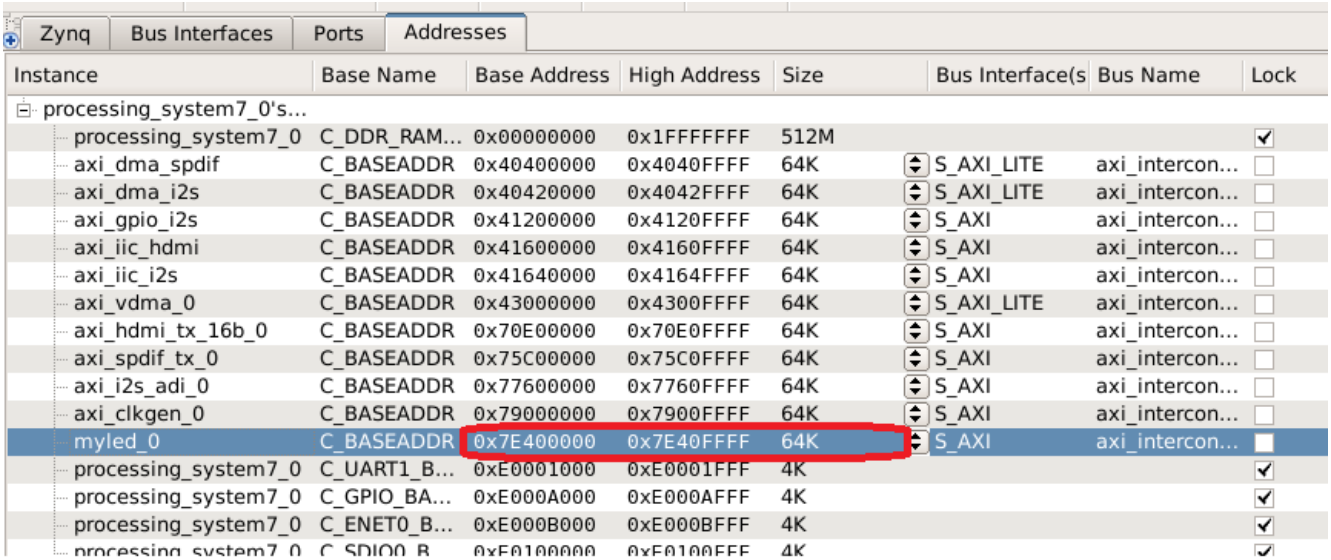
```
159     myled_proc_entry = proc_create(DRIVER_NAME, 0, NULL,
160                         &proc_myled_operations);
161     if (myled_proc_entry == NULL) {
162         dev_err(&pdev->dev, "Couldn't create proc entry\n");
163         ret = -ENOMEM;
164         goto err_create_proc_entry;
165     }
166
167     printk(KERN_INFO DRIVER_NAME " probed at VA 0x%08lx\n",
168             (unsigned long) base_addr);
169
170     return 0;
171
172  err_create_proc_entry:
173     iounmap(base_addr);
174  err_release_region:
175     release_mem_region(res->start, remap_size);
176
177     return ret;
178 }
179
180 /* device match table to match with device node in device tree */
181 static const struct of_device_id myled_of_match[] __devinitconst = {
182     {.compatible = "dglnt,myled-1.00.a"},
183     {},
184 };
185
186 MODULE_DEVICE_TABLE(of, myled_of_match);
187
188 /* platform driver structure for myled driver */
189 static struct platform_driver myled_driver = {
190     .driver = {
191             .name = DRIVER_NAME,
192             .owner = THIS_MODULE,
193             .of_match_table = myled_of_match},
194     .probe = myled_probe,
195     .remove = __devexit_p(myled_remove),
196     .shutdown = __devexit_p(myled_shutdown)
197 };
198
199 /* Register myled platform driver */
200 module_platform_driver(myled_driver);
201
202 /* Module Infomations */
203 MODULE_AUTHOR("Digilent, Inc.");
204 MODULE_LICENSE("GPL");
205 MODULE_DESCRIPTION(DRIVER_NAME ": MYLED driver (Simple Version)");
206 MODULE_ALIAS(DRIVER_NAME);
207
```

VI-4 Compile and generate the driver module using make (as shown in Example 23).

Example 23

```
[tinghui.wang@DIGILENT_LINUX drivers]$ make ARCH=arm CROSS_COMPILE=arm-xilinx-linux-gnueabi-
make -C ../linux-digilent/
M=/home/tinghui.wang/Workspace/ZedBoard/Project/14_4/Tutorial/drivers modules
make[1]: Entering directory
`/home/tinghui.wang/Workspace/ZedBoard/Project/14_4/Tutorial/linux-digilent'
  CC [M]  /home/tinghui.wang/Workspace/ZedBoard/Project/14_4/Tutorial/drivers/myled.o
  Building modules, stage 2.
  MODPOST 1 modules
  CC      /home/tinghui.wang/Workspace/ZedBoard/Project/14_4/Tutorial/drivers/myled.mod.o
  LD [M]  /home/tinghui.wang/Workspace/ZedBoard/Project/14_4/Tutorial/drivers/myled.ko
make[1]: Leaving directory
`/home/tinghui.wang/Workspace/ZedBoard/Project/14_4/Tutorial/linux-digilent'
[tinghui.wang@DIGILENT_LINUX drivers]$
```

VI-5 We need to add the **myled** device node into the device tree. Make a copy of the default device tree source in the `drivers` folder, and modify it according to Example 24. The compatibility string of the node is the same as we define in the driver source code (myled.c: line 182). The reg property defines the physical address space of the node. The address here should match with the address of the myled IP core in the address tab of the EDK design, as shown in Figure 44.



Instance	Base Name	Base Address	High Address	Size	Bus Interface(s	Bus Name	Lock
processing_system7_0's...							
processing_system7_0	C_DDR_RAM...	0x00000000	0x1FFFFFFF	512M			☑
axi_dma_spdif	C_BASEADDR	0x40400000	0x4040FFFF	64K	S_AXI_LITE	axi_intercon...	☐
axi_dma_i2s	C_BASEADDR	0x40420000	0x4042FFFF	64K	S_AXI_LITE	axi_intercon...	☐
axi_gpio_i2s	C_BASEADDR	0x41200000	0x4120FFFF	64K	S_AXI	axi_intercon...	☐
axi_iic_hdmi	C_BASEADDR	0x41600000	0x4160FFFF	64K	S_AXI	axi_intercon...	☐
axi_iic_i2s	C_BASEADDR	0x41640000	0x4164FFFF	64K	S_AXI	axi_intercon...	☐
axi_vdma_0	C_BASEADDR	0x43000000	0x4300FFFF	64K	S_AXI_LITE	axi_intercon...	☐
axi_hdmi_tx_16b_0	C_BASEADDR	0x70E00000	0x70E0FFFF	64K	S_AXI	axi_intercon...	☐
axi_spdif_tx_0	C_BASEADDR	0x75C00000	0x75C0FFFF	64K	S_AXI	axi_intercon...	☐
axi_i2s_adi_0	C_BASEADDR	0x77600000	0x7760FFFF	64K	S_AXI	axi_intercon...	☐
axi_clkgen_0	C_BASEADDR	0x79000000	0x7900FFFF	64K	S_AXI	axi_intercon...	☐
myled_0	C_BASEADDR	0x7E400000	0x7E40FFFF	64K	S_AXI	axi_intercon...	☐
processing_system7_0	C_UART1_B...	0xE0001000	0xE0001FFF	4K			☑
processing_system7_0	C_GPIO_BA...	0xE000A000	0xE000AFFF	4K			☑
processing_system7_0	C_ENET0_B...	0xE000B000	0xE000BFFF	4K			☑
processing_system7_0	C_SDIO0_B...	0xE0100000	0xE0100FFF	4K			☑

Figure 44. Physical Address for myled IP Core

Example 24 – Command Line

```
[tinghui.wang@DIGILENT_LINUX drivers]$ cp ../linux-digilent/arch/arm/boot/dts/digilent-
zed.dts ./
[tinghui.wang@DIGILENT_LINUX drivers]$ vim digilent-zed.dts
```

Example 24 – digilent-zed.dts

```
549             spi-speed-hz = <4000000>;
550             spi-sclk-gpio = <&ps7_gpio_0 59 0>;
551             spi-sdin-gpio = <&ps7_gpio_0 60 0>;
552         };
553
554         myled {
555             compatible = "dglnt,myled-1.00.a";
556             reg = <0x7e400000 0x10000>;
557         };
558     };
559 };
```

VI-6 Recompile the device tree blob as shown in Example 25.

Example 25

```
[tinghui.wang@DIGILENT_LINUX drivers]$ ../linux-digilent/scripts/dtc/dtc -I dts -O dtb -o
devicetree.dtb digilent-zed.dts
DTC: dts->dtb  on file "digilent-zed.dts"
[tinghui.wang@DIGILENT_LINUX drivers]$
```

VI-7 Copy these two files to the first partition of the SD card, as shown in Example 26. We are ready to test our driver on-board now.

Example 26.

```
[tinghui.wang@DIGILENT_LINUX drivers]$ ls
devicetree.dtb    Makefile       Module.symvers  myled.ko     myled.mod.o
digilent-zed.dts  modules.order  myled.c         myled.mod.c  myled.o
[tinghui.wang@DIGILENT_LINUX drivers]$ cp myled.ko /media/ZED_BOOT/d
[tinghui.wang@DIGILENT_LINUX drivers]$ cp devicetree.dtb /media/ZED_BOOT/
[tinghui.wang@DIGILENT_LINUX drivers]$
```

VI-8 Plug the SD card into the ZedBoard, and we can start testing our driver. Use the **insmod** command to install the driver module into the kernel. After the driver is installed, an entry named **myled** will be created under the `/proc` file system. Writing `0x0F` to `/proc/myled` will light up **LED 0~3**, while writing `0xF0` will light up **LED 4~7**. You can either remove the driver with command **rmmod** or power off the system by command **poweroff**. In both case, all the LEDs will be turned off, as shown in Example 27. For instructions on using the terminal with the ZedBoard, please refer to Step V-4 or Section **Boot from SD** in **Getting Started with Embedded Linux – ZedBoard**.

Example 27 – RAMDISK

```
U-Boot 2012.04.01-dirty (Feb 01 2013 - 12:52:36)

DRAM:  512 MiB
WARNING: Caches not enabled
MMC:   SDHCI: 0
Using default environment
...
reading zImage

2457328 bytes read
reading devicetree.dtb

9728 bytes read
reading ramdisk8M.image.gz

3694108 bytes read
## Starting application at 0x00008000 ...
Uncompressing Linux... done, booting the kernel.
[    0.000000] Booting Linux on physical CPU 0
[    0.000000] Linux version 3.6.0-digilent-13.01-00002-g06b3889
(tinghui.wang@DIGILENT_LINUX) (gcc version 4.6.3 (Sourcery CodeBench Lite 2012.03-79) ) #1
SMP PREEMPT Sun Feb 10 23:54:12 PST 2013
...
rcS Complete
zynq> mount /dev/mmcblk0p1 /mnt/
zynq> cd /mnt/
zynq> ls
BOOT.BIN             devicetree.dtb       ramdisk8M.image.gz
myled.ko             zImage
zynq> insmod myled.ko
[  122.160000] myled probed at va 0xe0d20000
zynq> ls /proc
1              567            9              fs             partitions
10             582            asound         interrupts     scsi
11             588            buddyinfo      iomem          self
12             594            bus            ioports        slabinfo
13             595            cmdline        irq            softirqs
14             596            config.gz      kallsyms       stat
15             6              consoles       kmsg           swaps
2              608            cpu            kpagecount     sys
3              614            cpuinfo        kpageflags     sysvipc
317            615            crypto         loadavg        timer_list
318            621            device-tree    locks          tty
333            641            devices        meminfo        uptime
4              642            diskstats      misc           version
429            643            dma            modules        vmallocinfo
440            647            dri            mounts         vmstat
441            652            driver         mtd            zoneinfo
5              653            execdomains    myled
515            7              fb             net
548            8              filesystems    pagetypeinfo
zynq> echo 0x0F > /proc/myled
zynq> cat /proc/myled
0x0f
zynq> echo 0xF0 > /proc/myled
zynq> cat /proc/myled
0xf0
zynq> mkdir -p /lib/modules/`uname -r`
zynq> cp myled.ko /lib/modules/`uname -r`
zynq> rmmod myled
```

Example 27 – Linaro FS

```
U-Boot 2012.04.01-dirty (Feb 01 2013 - 12:52:36)

DRAM:  512 MiB
WARNING: Caches not enabled
MMC:   SDHCI: 0
...
reading zImage

2457328 bytes read
reading devicetree.dtb

9728 bytes read
reading ramdisk8M.image.gz

3694108 bytes read
## Starting application at 0x00008000 ...
Uncompressing Linux... done, booting the kernel.
[    0.000000] Booting Linux on physical CPU 0
[    0.000000] Linux version 3.6.0-digilent-13.01-00002-g06b3889
(tinghui.wang@DIGILENT_LINUX) (gcc version 4.6.3 (Sourcery CodeBench Lite 2012.03-79) ) #1
SMP PREEMPT Sun Feb 10 23:54:12 PST 2013
...
Last login: Thu Jan  1 00:00:10 UTC 1970 on tty1
cat: /var/lib/update-notifier/fsck-at-reboot: No such file or directory
run-parts: /etc/update-motd.d/98-fsck-at-reboot exited with return code 1
Welcome to Linaro 12.11 (GNU/Linux 3.6.0-digilent-13.01-00002-g06b3889 armv7l)

 * Documentation:  https://wiki.linaro.org/

0 packages can be updated.
0 updates are security updates.

root@linaro-ubuntu-desktop:~# mount /dev/mmcblk0p1 /mnt/
root@linaro-ubuntu-desktop:~# cd /mnt/
root@linaro-ubuntu-desktop:/mnt# insmod myled.ko
root@linaro-ubuntu-desktop:/mnt# ls /proc
1     1357  1981  2088  2189  2345  514  asound       fs          pagetypeinfo
10    1367  1983  2101  2194  2440  547  buddyinfo    interrupts  partitions
1054  1369  1993  2104  2200  2452  548  bus          iomem       scsi
11    1372  1995  2105  2211  2464  565  cmdline      ioports     self
1112  1378  1999  2113  2223  2488  568  config.gz    irq         slabinfo
1128  1379  2     2116  2225  2536  589  consoles     kallsyms    softirqs
1129  1380  2011  2119  2226  2547  591  cpu          kmsg        stat
1177  14    2017  2125  2228  2562  594  cpuinfo      kpagecount  swaps
1178  1408  2036  2133  2246  2574  597  crypto       kpageflags  sys
1199  1450  2064  2135  2260  2594  598  device-tree  loadavg     sysvipc
12    15    2066  2137  2262  3     6    devices      locks       timer_list
1228  1625  2072  2149  2268  317   603  diskstats    meminfo     tty
1236  1637  2073  2152  2271  318   669  dma          misc        uptime
1240  1730  2078  2153  2277  333   676  dri          modules     version
1243  1837  2079  2155  2279  4     7    driver       mounts      vmallocinfo
1284  1966  2080  2157  2294  439   737  execdomains  mtd         vmstat
13    1969  2085  2159  2320  440   8    fb           myled       zoneinfo
1354  1970  2086  2161  2340  5     9    filesystems  net
root@linaro-ubuntu-desktop:/mnt# echo 0x0F > /proc/myled
root@linaro-ubuntu-desktop:/mnt# echo 0xF0 > /proc/myled
root@linaro-ubuntu-desktop:/mnt# rmmod myled
root@linaro-ubuntu-desktop:/mnt#
```

Section VII: User Application

Prerequisites

- **Xilinx ISE DS 14.4 (WebPack)**
  available at Xilinx Website Download Page

Instructions

VII-1 In this section, we will write a user application that makes the LEDs blink by writing to /proc/myled. Create a directory named **user_app** in the Tutorial folder, as shown in Example 28. Inside the **user_app** directory, we will compose the led_blink.c, as shown in Example 29.

Example 28.

```
[tinghui.wang@DIGILENT_LINUX Tutorial]$ mkdir user_app
[tinghui.wang@DIGILENT_LINUX Tutorial]$ ls
devicetree.dtb  drivers   inux-digilent  u-boot-digilent  user_app  ZedBoard_Linux_Design
[tinghui.wang@DIGILENT_LINUX Tutorial]$
```

Example 29 – Command Line.

```
[tinghui.wang@DIGILENT_LINUX user_app]$ vim led_blink.c
```

Example 29 – led_blink.c.

```
 0 #include <stdio.h>
 1 #include <stdlib.h>
 2 #include <unistd.h>
 3
 4 int main()
 5 {
 6     FILE* fp;
 7     while(1) {
 8         fp = fopen("/proc/myled", "w");
 9         if(fp == NULL) {
10             printf("Cannot open /proc/myled for write\n");
11             return -1;
12         }
13         fputs("0x0F\n", fp);
14         fclose(fp);
15         sleep(1);
16         fp = fopen("/proc/myled", "w");
17         if(fp == NULL) {
18             printf("Cannot open /proc/myled for write\n");
19             return -1;
20         }
21         fputs("0x00\n", fp);
22         fclose(fp);
23         sleep(1);
24     }
25     return 0;
26 }
```

VII-2 Compose a Makefile and compile led_blink.c into led_blink.elf, as shown in Example 30.

Example 30 – Command Line.

```
[tinghui.wang@DIGILENT_LINUX user_app]$ vim Makefile
```

Example 30 – Makefile.

```
1  CC = arm-xilinx-linux-gnueabi-gcc
2  CFLAGS = -g
3
4  all : led_blink
5
6  led_blink : led_blink.o
7      ${CC} ${CFLAGS} -o $^ $@
8
9  clean :
10     rm -rfv *.o
11     rm -rfv led_blink
12
13 .PHONY : clean
```

Example 30 – Compile led_blink.

```
[tinghui.wang@DIGILENT_LINUX user_app]$ make
arm-xilinx-linux-gnueabi-gcc -g   -c -o led_blink.o led_blink.c
arm-xilinx-linux-gnueabi-gcc -g -o led_blink led_blink.o
[tinghui.wang@DIGILENT_LINUX user_app]$ ls
led_blink  led_blink.c  led_blink.o  Makefile
[tinghui.wang@DIGILENT_LINUX user_app]$
```

VII-3 Insert the SD card into the computer, and copy the binary file led_blink onto the first partition of SD card, as shown in Example 31.

Example 31.

```
[tinghui.wang@DIGILENT_LINUX user_app]$ cp led_blink /media/ZED_BOOT/
```

VII-4 Plug the SD card into the ZedBoard. Use the **insmod** command to install the driver module into the kernel. Run led_blink and the LED will start blinking.

Example 32 – RAMDISK

```
...
rcS Complete
zynq> mount /dev/mmcblk0p1 /mnt/
zynq> cd /mnt/
zynq> ls
BOOT.BIN             devicetree.dtb       led_blink
myled.ko             ramdisk8M.image.gz   zImage
zynq> insmod myled.ko
[  122.160000] myled probed at va 0xe0d20000
zynq> ./led_blink
^C
zynq> mkdir -p /lib/modules/`uname -r`
zynq> cp myled.ko /lib/modules/`uname -r`
zynq> rmmod myled
```

Example 32 – Linaro FS

```
...
root@linaro-ubuntu-desktop:~# mount /dev/mmcblk0p1 /mnt/
root@linaro-ubuntu-desktop:~# cd /mnt/
root@linaro-ubuntu-desktop:/mnt# insmod myled.ko
root@linaro-ubuntu-desktop:/mnt# ./led_blink
^C
root@linaro-ubuntu-desktop:/mnt# rmmod myled
root@linaro-ubuntu-desktop:/mnt#
```